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THE FLORIDA STATE UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

IMPACT OF ENSO ON WEATHER CONDITIONS AT CONTINENTAL UNITED STATES MILITARY BASES

By
SHANNON R. SWEENY
CAPT, USAF

A Thesis submitted to the
Department of Meteorology
in partial fulfillment of the
requirements for the degree of
Masters of Science

Degree Awarded:
Summer, 1996

The members of the Committee approve the thesis of Shannon R. Sweeny defended on May 30, 1996.

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ABSTRACT

The climatic response to ENSO events is assessed at continental U.S. military bases for fog, Instrument Flight Rule conditions, snow and freezing rain. Forty-five years of monthly data are classified as El Niño (warm phase), El Viejo (cold phase), or Neutral (neither) according to sea surface temperature anomalies in the central equatorial Pacific.

The seasonal data are resampled to estimate population distributions for each of 10, three month seasons in an ENSO year. The difference in means between El Niño (El Viejo), and Neutral events are determined. Conditional probabilities (the probability that a three month seasonal mean for El Niño (El Viejo) will exceed the long-term mean plus one standard deviation) are calculated for all 10 seasons for each climate variable. The results indicate that there are fewer occurrences of fog in both El Niño and El Viejo years than Neutral years, with a few exceptions. Given an El Niño year, fewer IFR hours occur across the entire country, however, during El Viejo years more (fewer) IFR hours occur at military bases in the east (west). The frequency of snow during an El Niño year is dependent on location, but during an El Viejo year fewer (more) hours of snow occur in the east (west). Freezing rain events occur so infrequently that the method could only be applied in a few cases. El Viejo years have more freezing rain events than El Niño years, and the mid-West region has the highest probability of freezing rain events during an El Viejo year.

The results are generally consistent with the large scale circulations associated with ENSO, such as the PNA and "reverse PNA" patterns.

1. INTRODUCTION

Weather and climate effect our daily lives in ways that often go unnoticed by the general public. Variations in climate can significantly effect operations of our modern military. "In military operations, weather is the first step in planning and the final determining factor in execution of any mission..." General Carl Spaatz, Air Force Chief of Staff, 1948. Although most of today's military equipment is designed to operate regardless of foul weather, day to day military operations can still be significantly impacted by inclement conditions such as dense fog or freezing rain. Mother nature still has the ability to stall and potentially cripple operations. A recent example was the delayed deployment of US troops to Bosnia due to fog (Jan. 1996). For effective operational planning and efficient use of military resources, knowledge of climate variability associated with El Niño-Southern Oscillation (ENSO) is valuable.

El Niño and the Southern Oscillation (SO) were considered two independent phenomena prior to 1969. El Niño referred to the anomalously warm water which appeared along the Peru/Ecuador coast periodically at Christmas (Philander, 1990). Interest in the Southern Oscillation, the interannual pressure fluctuations between the Indian Ocean and eastern tropical Pacific, was initiated by Walker in the 1920's. Bjerknes synthesized these ideas in 1969 by proposing a physical relationship between the ocean and atmosphere which linked El Niño and the Southern Oscillation. Today ENSO refers to the anomalous warming or

cooling of the tropical Pacific and the complex coupled air-sea interactions that follow.

The character of ENSO covers a wide spectrum. ENSO oscillates on interannual time scales between warm events and cold events (Zebiak and Cane, 1987). The evolution of an ENSO event is summarized by Rasmusson and Carpenter (1982), Hamilton (1988), and Philander (1990). Easterly trade winds weaken to the west of the dateline at the end of the year preceding a warm event. A westerly wind anomaly develops and excites a Kelvin wave which depresses the thermocline as it travels eastward along the equator. The increased thickness of the upper mixed layer causes a sea surface temperature (SST) anomaly to develop in the eastern equatorial Pacific during the onset year of a warm event. The warm anomalies spread westward and extend over a large region of the equatorial Pacific by the end of the onset year. The mature phase refers to the Northern Hemisphere winter following the onset. The strongest extra-tropical teleconnections are observed during the boreal winter of the mature phase.

A composite picture of the typical warm event was built by Rasmusson and Carpenter (1982). This character sketch identifies common features among warm events. However, no two warm events are identical. Quinn et al., (1987) details this in a classification of moderate, strong and very strong warm events over the last 450 years. Solow (1995) searches for, but does not find, a secular trend in the frequency of warm events in the historical record of Quinn et al.

During the warm phase of ENSO a pattern often evolves in the downstream sea-level pressure pattern, referred to as the Pacific North American pattern, PNA. The PNA pattern consists of a strong Aleutian low in the Gulf of Alaska, a ridge in western North America and a trough in eastern North America. Both

Ropelewski and Halpert (1986) and Yarnal and Diaz (1986) conclude that although the PNA pattern is one of the normal modes of atmospheric variability, it occurs most often in conjunction with ENSO episodes. Yarnal and Diaz introduce the idea that a "reverse PNA" pattern occurs during ENSO cold events.

In addition to interest in understanding the physical processes of ENSO, there has been considerable research in its connection to other climatic events. The effects of ENSO have been studied on both global and regional scales. ENSO was initially documented on a global scale by Walker and Bliss (1932). ENSO related North American and global precipitation patterns were recently identified by Ropelewski and Halpert (1986, 1987). Kiladis and Diaz (1989) distinguish differences in temperature and precipitation anomalies which occur during both warm and cold events at several hundred locations around the world. Halpert and Ropelewski (1992) distinguish 12 regions around the world with a statistically significant (at the 99% level) relationship between surface temperature and the low phase of the Southern Oscillation. In addition, they also identify 8 regions with a 99% significant relationship between surface temperature and the high phase of the Southern Oscillation (ENSO cold event).

Analysis of the relationship between ENSO and surface parameters has focused on precipitation and temperature anomalies. The North American temperature response to ENSO has been well documented (Ropelewski and Halpert, 1986, 1992; Kiladis and Diaz, 1989; Hamilton, 1989; Sittel, 1994a). Ropelewski and Halpert (1986) determine that temperature response for warm events in northwest North America is strongest from December through March and strongest in the southeast US from October through March. Their results, above normal temperatures in Alaska and western Canada and below normal

temperatures in the southeastern US, are consistent with the PNA pattern (Ropelewski and Halpert, 1986).

The precipitation response in North America is also well documented (Ropelewski and Halpert, 1986; Yarnal and Diaz, 1986). Douglas and Englehart (1981) show a statistical relationship between autumn rain in the central equatorial Pacific and increased winter precipitation in south-central Florida. Results from Sittel (1994b) indicate that the southeastern United States is cool and wet during ENSO warm event winters and warm and dry during ENSO cold events winters. However, precipitation anomalies are not as easily accounted for by the PNA pattern. Ropelewski and Halpert (1986) suggest that precipitation anomalies during warm events are the result of a northward displacement of the sub-tropical jet stream due to strengthened westerlies in the Gulf of Mexico. This is a more direct forcing than the PNA pattern. Yarnal and Diaz (1986) note that precipitation anomalies are sensitive to the precise arrangement of the longwave troughs and ridges in the PNA and "reverse PNA" patterns.

The purpose of this work is to examine climate variability patterns linked to ENSO events that could impact decisions related to the occurrence of conditions limiting military operations. ENSO's signature on the frequency of fog, freezing rain, snow and IFR conditions (low cloud ceilings, reduced visibility) are presented. Temperature and precipitation responses were also determined, but are well documented elsewhere and not critical to military operations. Therefore these climate variables are not discussed. Climate data are categorized as occurring during an ENSO warm event (El Niño), cold event, (El Viejo) or neither (Neutral), based on sea surface temperature (SST) anomalies in the central equatorial Pacific ocean. The data are resampled to build a climate scenario for each of ten three-month seasons for each category. The difference

of means between ENSO populations is calculated to illustrate the relationship between the ENSO extremes and Neutral conditions. Conditional probabilities are computed to determine the probability that the mean of the resampled distribution will be greater (less) than the mean plus (minus) one standard deviation of the distribution comprised of all 45 years of data.

2. DATA

Four climate variables are examined; fog, snow, freezing rain and IFR conditions. Instrument Flight Rules, IFR, conditions exist when the cloud ceiling height is below 1000 feet and visibility between one and three miles. The climate variables were chosen because they impact operations at military facilities.

Data from 46 military stations (4 Army bases, 2 Navy bases, 39 Air Force bases, and 1 Marine Corp. base) were obtained from the Air Force Combat Climatology Center (AFCCC) at Scott AFB, IL.

The data are monthly averages of the number of reported hours of fog, IFR conditions, snow and freezing rain. These were recalculated as the percentage of hours per month in which the variable was recorded in the hourly observations. For example, during January 1948 Andrews AFB, MD reported fog in 108 hourly observations. This equates to 14.5% of the total 744 hours in the month of January.

The spatial distribution of the stations indicates that the military bases are concentrated south of 37N and along the Atlantic coast (Fig. 1). There are two bases located in Alaska. All stations were not used in the analysis of each climate variable (Table 1). Stations were chosen based on the significance and frequency of the climate variable at a particular location. For instance, freezing rain was never reported at MacDill AFB, FL in the 45 year record. Therefore, MacDill AFB, was not included in the freezing rain analysis. A station's historical

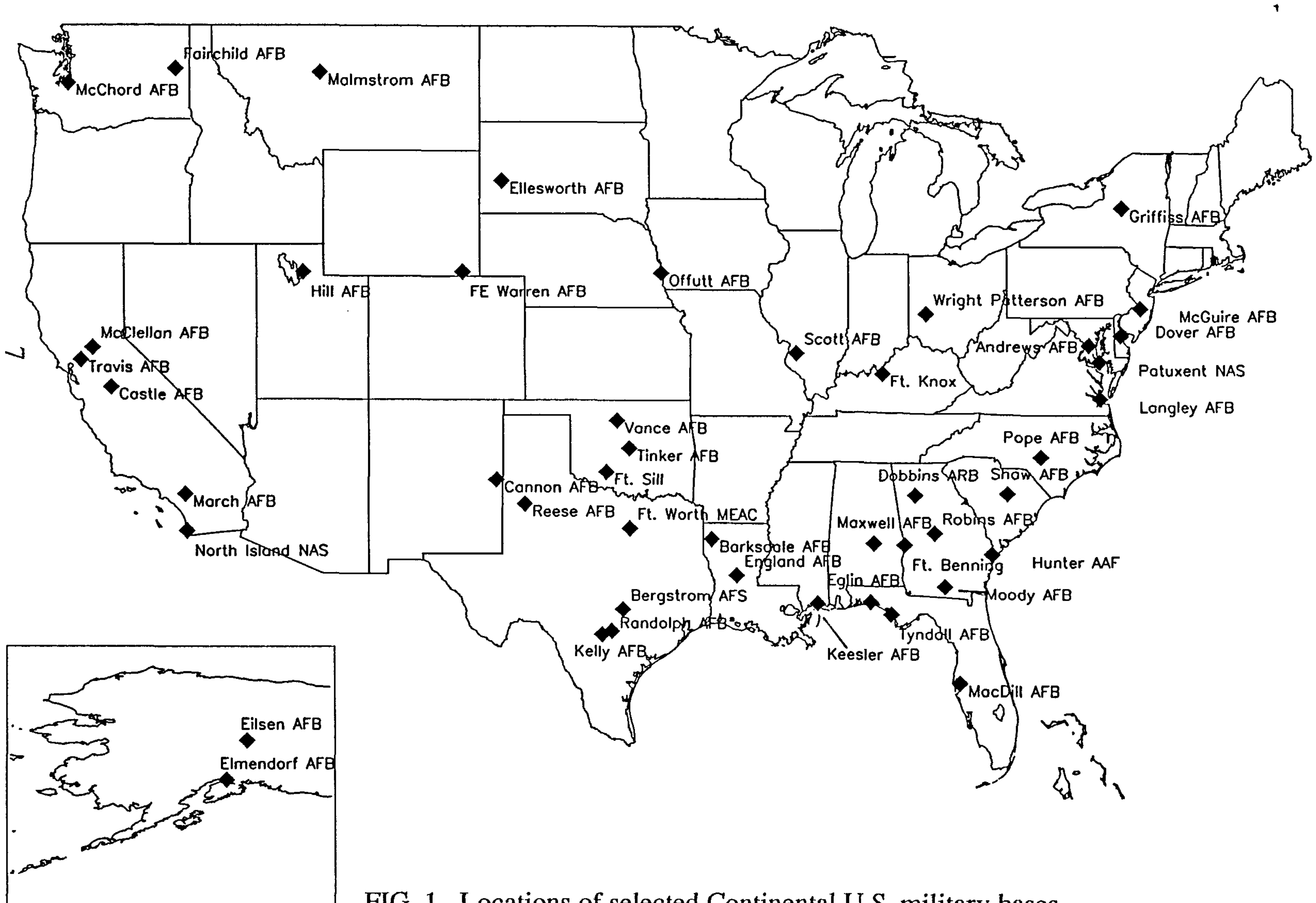


FIG. 1. Locations of selected Continental U.S. military bases.

record must have a minimum of 90% of it's record serially complete between 1948 and 1992 for inclusion. Most of the stations with incomplete records are missing data from the years 1971 and 1972. These two years comprise 4% of the record. The missing data are not filled in.

In order to assess the climate anomalies associated with ENSO events, the data are classified as an El Niño (warm event), El Viejo (cold event), or Neutral. The index employed for classifying the data is the Japanese Meteorological Agency Sea Surface Temperature Index, (JMA/SST). The JMA/SST index is built by calculating monthly mean SST anomalies averaged over the Pacific ocean from 4 N to 4 S and 150 W to 90 W. Then a 5-month running mean is applied to smooth out intraseasonal variations.

The method used for classifying years in the ENSO cycle is as follows. An ENSO year refers to the period from October through September. If the JMA/SST index is greater than +0.5 ^{o}C (-0.5 ^{o}C) for 6 consecutive months beginning before October and including October, November and December, then the year is classified as an El Niño (El Viejo). The remaining years not meeting the stated criteria are considered neutral years (Table 2). This classification method produces a partitioning of years which generally agrees with the classification based on the Southern Oscillation Index found in the literature (Ropelewski and Halpert, 1995; Kiladis and Diaz, 1989; Quinn et al., 1987) with the exception of 1953 which is classified as a warm event in the literature, but a neutral year under the criteria employed for this approach. The JMA/SST index was unavailable for the period 1947-1949. Index values for this missing period are constructed using data from the Comprehensive Ocean-Atmosphere Data Set (COADS) (Slutz et al 1985) and according to the index definition (Shriver, 1993).

3. METHOD

It is the goal of this research to examine the climate variables for each ENSO category (El Niño, El Viejo, and Neutral) during 10 three month seasons with overlapping months from October/November/December (OND) through July/August/September (JAS). There are 10 as opposed to 12 seasons in an ENSO year as a result of the overlapping. Characterizing the climate variables in three month seasons is useful for the practice of making seasonal outlooks (Ropelewski and Halpert, 1995). Comparisons will be made between each ENSO category for each season. For instance, a comparison can be made between the JFM season of El Niño years and the JFM season of El Viejo or Neutral years. This is accomplished by employing a resampling method to build a composite El Niño or El Viejo event for each season. From these composites, comparisons are made by determining the difference in means and conditional probabilities.

a. Resampling Method

Classifying the limited climate data examined here by ENSO category (El Niño, El Viejo, and Neutral) yields small samples from which to determine the statistical properties of the population. For instance, the mean January fog occurrence for El Niño years would be based only on 11 values (Table 2). Two problems arise when making inferences about a population mean from a small sample. A Gaussian assumption based on the Central Limit Theorem would be invalid for the sampling distribution, and the sample standard deviation cannot be assumed to be a good approximation for the population standard deviation

(McClave and Dietrich, 1994). Therefore, a resampling method is employed for estimating the statistical distribution of each of the three ENSO populations. Recently, resampling methods have been used successfully in many climate studies (Sittel, 1994a; Portman and Gutzler, 1996) For this study a resampling technique (Sittel, 1994a) was adapted from the bootstrap method (Efron, 1993). The resampling technique used here is analogous to the bootstrap in three ways. First, it constructs new synthesized data sets by sampling with replacement from the original data. Second, the test statistic of interest is computed for each new data set. Third, the process is repeated numerous times to build a distribution of the test statistic. The test statistic of interest for this study is the mean. For the resampling method used here, the mean of the distribution of resampled data sets is equivalent to the mean of the original data. The basic difference between the bootstrap and the method used here is in the sample size of the synthesized data sets. The bootstrap method requires that the synthesized data sets be the same sample size as the original data. For the purposes of this research, the synthesized data sets are composed of three values, one for each month in the three month season. For example, a synthesized data set will be composed of one January value, one February value and one March value.

The details of the resampling technique employed in this research are as follows. First, each data value is categorized by month and ENSO category according to the JMA/SST index. For example, all January fog frequencies occurring during El Niño years go into one category, all February fog frequencies during El Niño years go into another category, etc. Next, three month seasonal averages are created by choosing one value randomly, with replacement, for each month in the season. For example, January 1957 might be averaged with February 1982 and March 1969 to obtain one sample representing the season

January/February/March (JFM) for El Niño years. In this way, new samples are generated from the original data set. This is repeated 10 000 times. The resulting distribution comprised of 10 000 points is representative of the JFM season for El Niño years. The process is repeated for each of the 10 seasons October/November/December (OND) through July/August/September (JAS), for all three ENSO categories.

b. The difference of the means

For each climate variable and season the difference between mean values for El Niño and Neutral cases as well as the difference between El Viejo and Neutral cases highlight overall patterns associated with ENSO phases (e.g. Fig 2).

A Monte Carlo experiment is performed to test the significance of the differences, and to quantify what probability is due to chance. The null hypothesis states that for the particular climate variable, there is no difference between the mean value for El Niño (El Viejo) years and the mean value for Neutral years. The apriori significance level is set at 0.1. Multiple tests are performed. To assure that the overall confidence level associated with the multiple tests remains at or above the 90% level, the significance level is adjusted according to the Bonferroni procedure (McClave and Dietrich, 1994). This procedure follows the formula:

$$100\left(1-\frac{\alpha}{\omega}\right)$$

where α is the apriori significance level and ω is the number of comparisons made. In this case, omega equals four to account for the four seasons of the year. The new, more stringent confidence level is 97.5%.

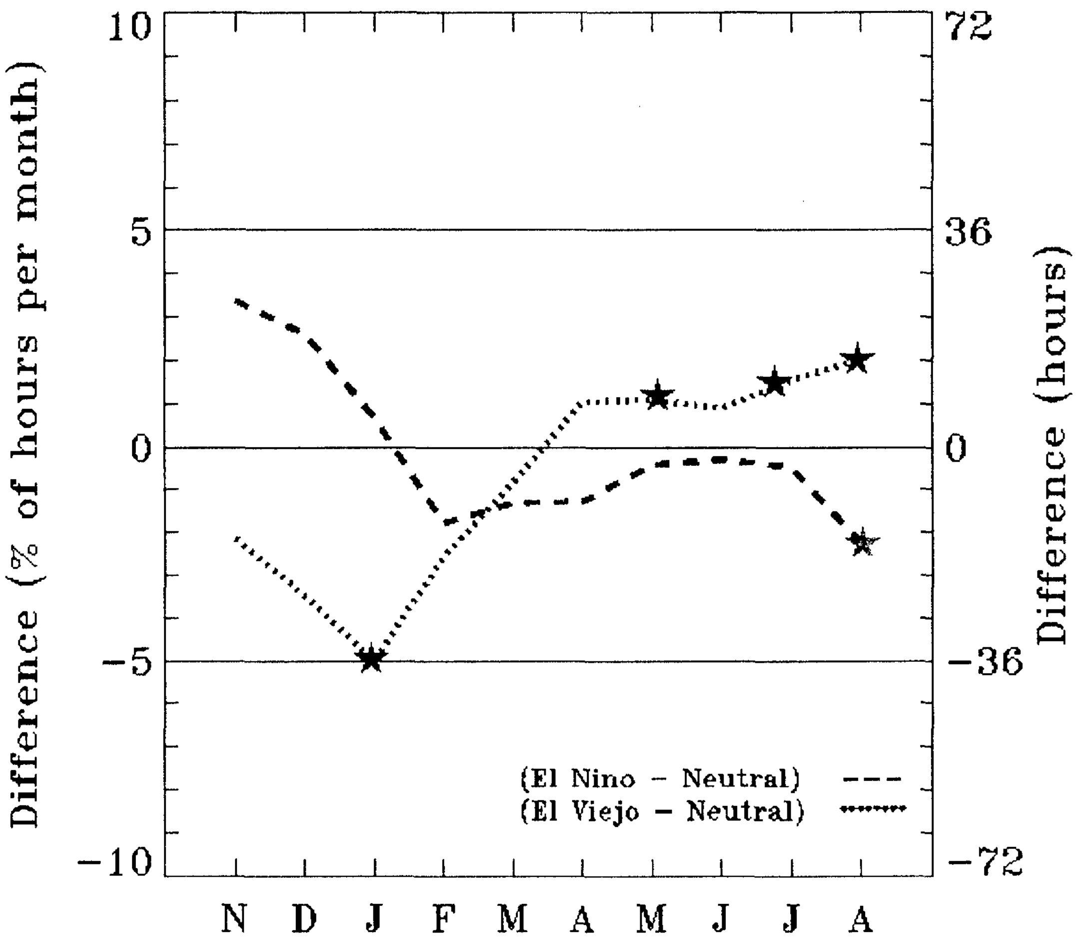


FIG. 2. Difference of means based on resampled data for fog at McChord AFB, WA. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Stars mark the seasons with a significant difference based on a two-tailed T-test using $\alpha = 0.05$.

The Monte Carlo experiment is completed to develop further the significance of the impact of ENSO on climate variables. Knowing that there are 11 El Niño years during the period 1948-1992, 11 years from the period are randomly assigned as El Niño. Likewise, 22 different random years are assigned as Neutral and the remaining 12 years are assigned as El Viejo. From this artificial set of El Niño, El Viejo and Neutral years, the mean for each category is computed. Then the difference between the El Niño (El Viejo) mean and Neutral mean is computed. This process is repeated 5,000 times to produce accuracy to the third decimal place. Now a comparison is made of the differences of means of the resampled data and the differences from the Monte Carlo experiment. Any difference of these means that falls outside of the confidence interval is considered significant. If the null hypothesis is rejected, then it can be said that changes in climate variables associated with ENSO during the particular season are statistically significant.

b. Conditional Probabilities

The shape of the histograms formed from the resampled data is important for determining conditional probabilities. Histograms plotted from the resampled data show a variety of distributions (e.g. Fig. 3). From an inspection of the histograms it is obvious that a Gaussian assumption cannot be made for all the climate data studied, because the distributions are not symmetric about the mean. The non-negative, positively skewed Weibull distribution was chosen to fit the histograms of resampled distributions of fog, snow, freezing rain and IFR conditions.

The Weibull distribution has been successfully applied to wind speed data (Pavia and O'Brien, 1986) and precipitation (Sittel, 1994a). Defined by a shape

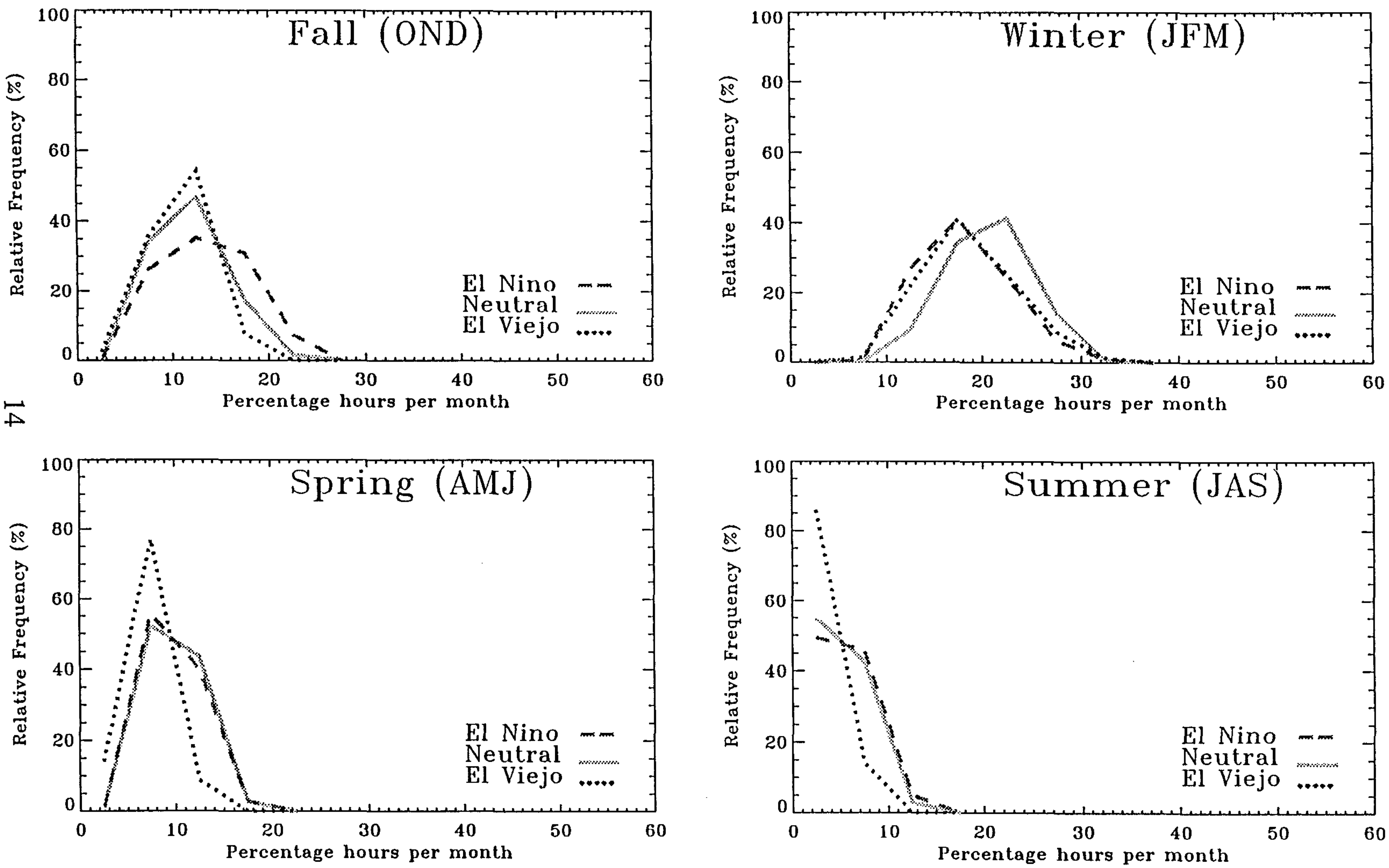


Fig. 3. Histograms of fog frequency at Eglin AFB, FL for 4 seasons of the year. Based on resampled historical data for each ENSO category.

parameter, A, and a scaling parameter, C, the Weibull distribution has the probability density function (PDF):

$$f(x)=\left(\frac{A}{C}\right)\left(\frac{x}{C}\right)^{A-1}\exp\left(-\left(\frac{x}{C}\right)^{A}\right) \qquad x,A,C>0$$

where x are the data to be fitted. If A<1, then f(x) is extremely positively skewed, but if A>1, then f(x) has a maximum value somewhere other than the origin. A=1, and A=3.6 are special cases of the Weibull distribution in which the function is exponential or Gaussian, respectively (Wilkes, 1995). The scaling parameter compresses or expands the distribution along the x axis. Another expedient aspect of the Weibull distribution is that it's PDF is analytically integrable, hence the cumulative distribution function (CDF) is:

$$F(x)=P(\mathrm{X}\le x)=1-\exp\left(-\left(\frac{x}{C}\right)^{A}\right)$$

which represents the probability that a random variable X is less than or equal to a specific value, x.

The procedure for fitting the Weibull distribution is as follows. First, a CDF is computed from the resampled data. Ten observed percentiles are determined at (5, 15, ..., 95) for the CDF. The Weibull distribution is fit at these ten points through least squares minimization. The fit is weighted evenly at all percentiles. The curve that best fits the resampled data is determined by searching for the shape and scaling parameter that minimizes the sum of the least squared error (Fig. 4). The goodness of fit for the Weibull distribution is the average error for all ten points. A value of 1.0 indicates a perfect fit. The climate variable with the best fit is fog, in which 87% of the curves fit greater than 0.95. The snow curves were fit at greater than 0.95, for 85% of the curves. For IFR, 76% of the curves fit greater than 0.95. The black sheep is freezing rain which only fit better than 0.95 for 13% of the curves.

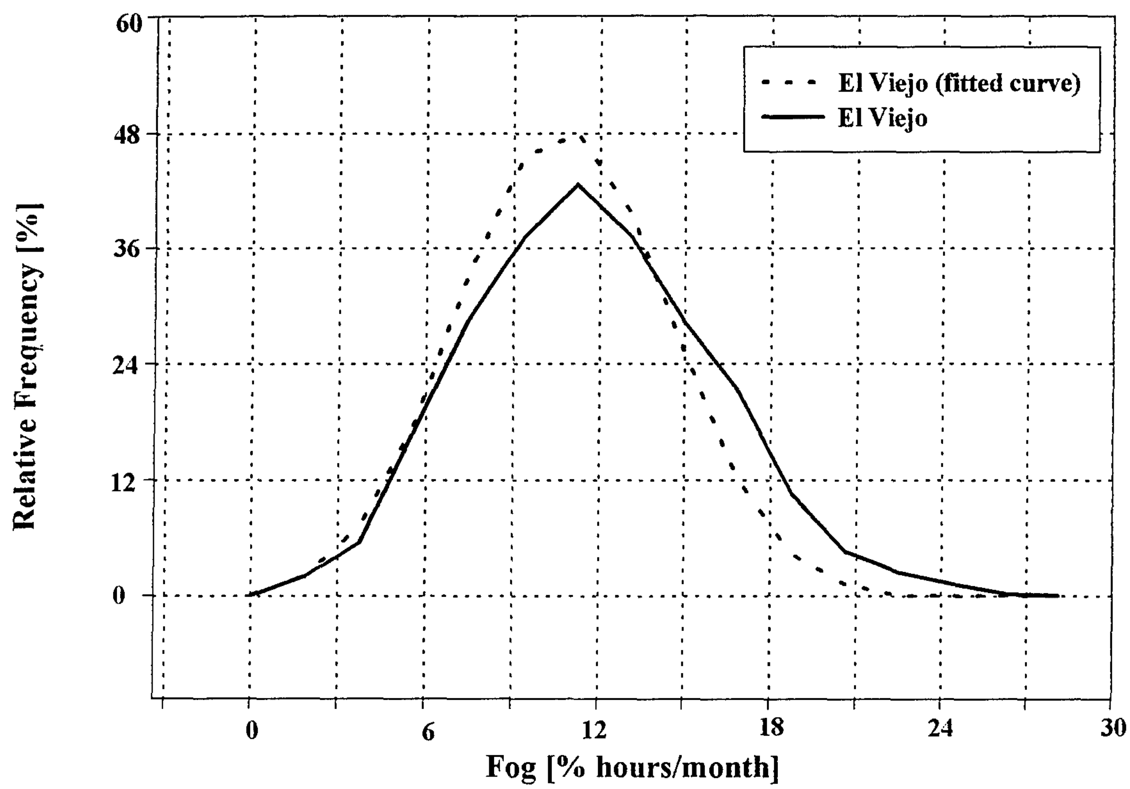


FIG 4. Example of the fitted Weibull curve for fog at Eglin AFB, FL during the OND season. Mean = 10.8%, standard deviation = 2.9%, shape parameter = 3.9, scaling parameter = 11.9.

The conditional probability is defined as the probability that a mean value for a particular climate variable from an El Niño (El Viejo) case is greater than one standard deviation above or below the mean for all years (Fig. 5). This statistic is meaningful, as an example, in assessing the probability that a particular military base will experience above normal amounts of a particular climate variable during an El Niño year or below normal amounts of during an El Viejo year.

To calculate the conditional probabilities, the mean and standard deviation of the climate variable are determined for a particular season over the entire period 1948-1992. The mean and standard deviation for the whole period are denoted, $\overline{X}_{all}$ and σ_{all}. The conditional probabilities are thus defined:

$$P(X > \overline{X}_{all} + \sigma_{all}) \text{ given El Niño (El Viejo)} \qquad (1)$$

$$P(X < \overline{X}_{all} - \sigma_{all}) \text{ given El Niño (El Viejo)} \qquad (2)$$

where X is the three month seasonal average of the resampled data for an ENSO category, El Niño or El Viejo. The corresponding probability formulas based on the Weibull distribution CDF are:

$$1 - \exp\left(-\left(\frac{\overline{X}_{all} + \sigma_{all}}{A}\right)^C\right) \qquad (3)$$

$$\exp\left(-\left(\frac{\overline{X}_{all} + \sigma_{all}}{A}\right)^C\right) \qquad (4)$$

where $\overline{X}_{all}$ and σ_{all} are previously defined, C is the scaling parameter for the Weibull distribution and A is the shape parameter.

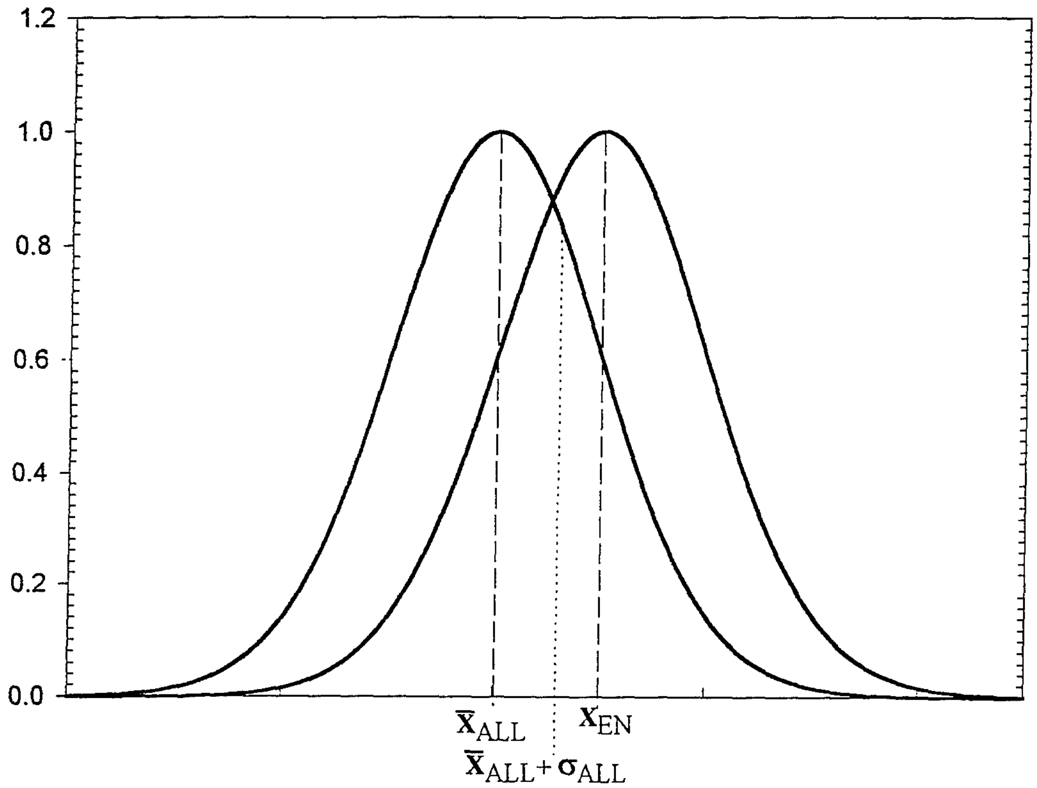


FIG. 5. Conditional probability illustration. Distribution of all years is on the left and the distribution of El Niño years is on the right. The conditional probability is the probability that the El Niño mean is greater than the mean plus one standard deviation of the distribution of all years $\left(\overline{X}_{all} + \sigma_{all}\right)$.

The combination of the resampling technique, the difference in means and the conditional probabilities, produce the results which define the role of ENSO on climate variables at US military bases.

4. RESULTS

This section is organized as follows. Each climate variable is discussed in a separate sub-section. For each climate variable, one representative station is chosen to illustrate how the different statistical analyses are used together to draw conclusions about that climate variable. Four of the ten seasons are examined with a histogram portraying the distributions of the three ENSO populations for each season; fall, winter, spring, and summer. A difference plot illustrates the relationship between the El Niño (El Viejo) mean and the Neutral mean for each season. A conditional probability plot reveals the seasonally varying probabilities of a climate variable being greater or less than the mean plus or minus one standard deviation of the distribution of all years. A summary of the conditional probability results for each climate variable during the winter season, JFM, appears in the Appendix. Next, the discussion is generalized to include results from all stations. Possible explanations associating the synoptic scale circulations with the results are briefly explored.

a. Fog

Fog is important to military airlift operations. All aircraft have visibility requirements for take-off and landing. Generally, larger, slower aircraft require more visible runway. Hence, fog can seriously delay flying schedules.

Dover AFB, DE operates the largest aerial port on the east coast. In addition, it is home to 436th Airlift Wing which operates C-5's, the largest transport aircraft in the Air Force inventory. The C-5 requires an 8,300 foot

runway for take-off (USAF Almanac, 1996). Hence, fog can be critical for operations at this base.

The populations for El Niño, El Viejo and Neutral cases at Dover AFB, Delaware are uniquely distributed in the fall and spring (Fig. 6). All three populations are very similar in the winter. The El Niño and El Viejo curves for the summer are nearly identical and both lie to the left of the neutral curve.

Differences of mean values vary seasonally (Fig. 7). During El Niño years, less fog occurs than during Neutral years, in the fall and winter. The El Niño differences for the seasons NDJ, DJF, and JFM are significant above the 97.5% confidence level (Table 3). During the spring months, particularly March through May, approximately 26 more hours of fog occur per month in El Niño years than during Neutral years. Although the El Viejo differences are small and less variable than the El Niño differences, every season throughout the year has fewer hours of fog than Neutral years.

The conditional probabilities support previous results at Dover AFB. Given an El Niño year, the probability is 35% that at least 153 hours (6.3 days) of fog per month will occur in the spring (Fig. 8a). This is 44 more hours than an average month. While El Niño probabilities have one large peak during the year, the impact of El Viejo on reducing fog sustains a probability between 19% and 37% for the entire year (Fig. 8b). For the case of MAM given an El Viejo year, there is a 37% probability that fewer than 65 hours of fog will occur per month. Hence, at Dover AFB, as few as 65 hours or as many as 153 hours of fog could occur based on the phase of ENSO.

Examining the results for all of the stations, some interesting regional similarities are apparent (Table 4). Like Dover AFB, DE, the stations located in mid-Atlantic states including McGuire AFB, NJ, Andrews AFB, MD, Patuxent NAS,

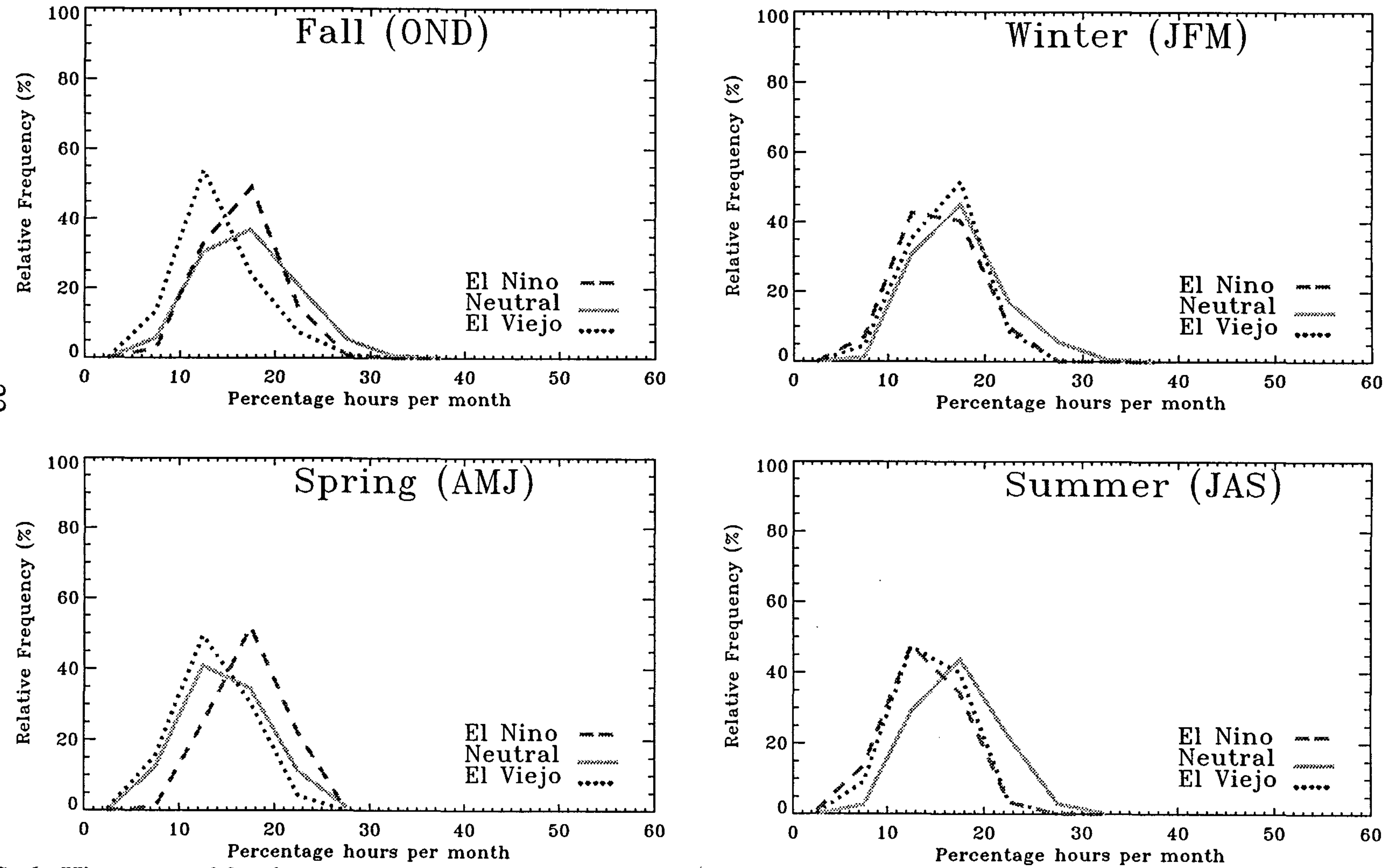


FIG. 6. Histogram of fog frequency at Dover AFB, DE for 4 seasons of the year. Based on resampled historical data for each ENSO category.

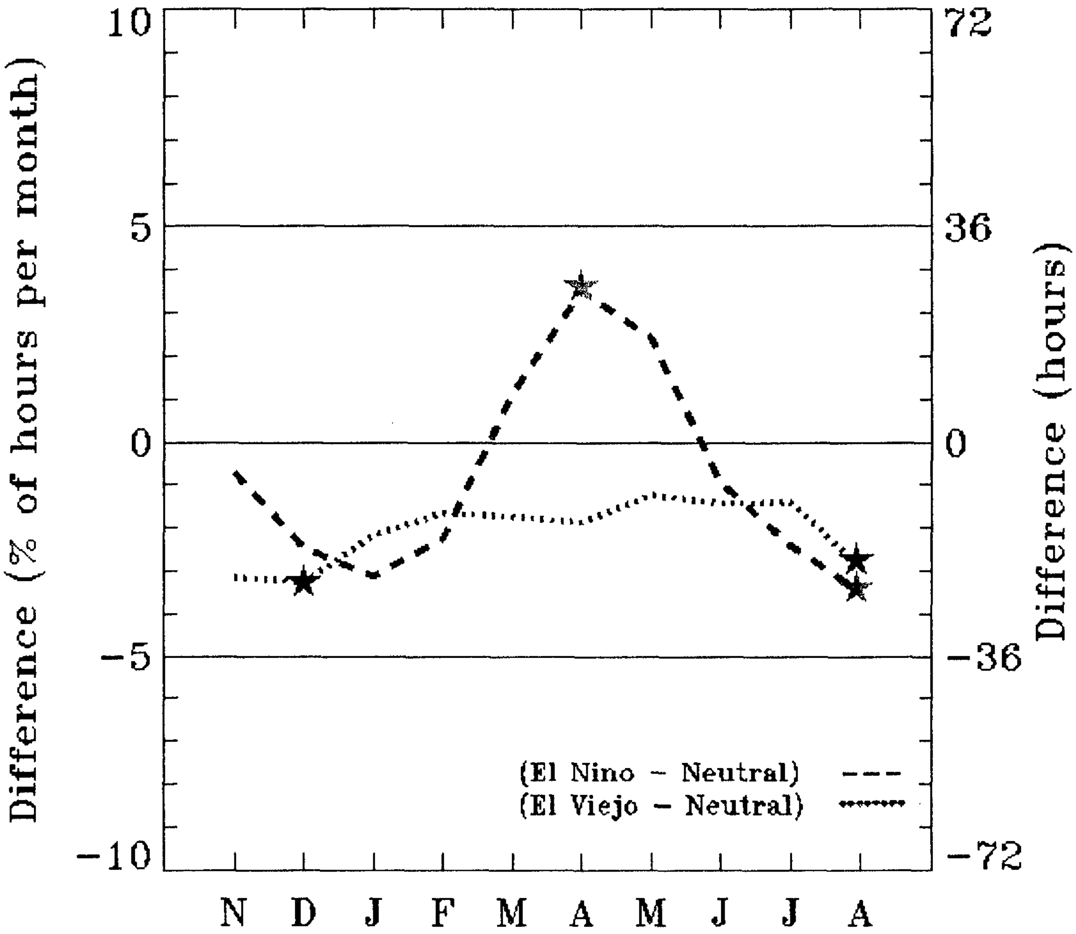


FIG. 7. Difference of means based on resampled data for fog at Dover AFB, DE. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Stars mark the seasons with a significant difference based on a two-tailed T-test using $\alpha = 0.05$.

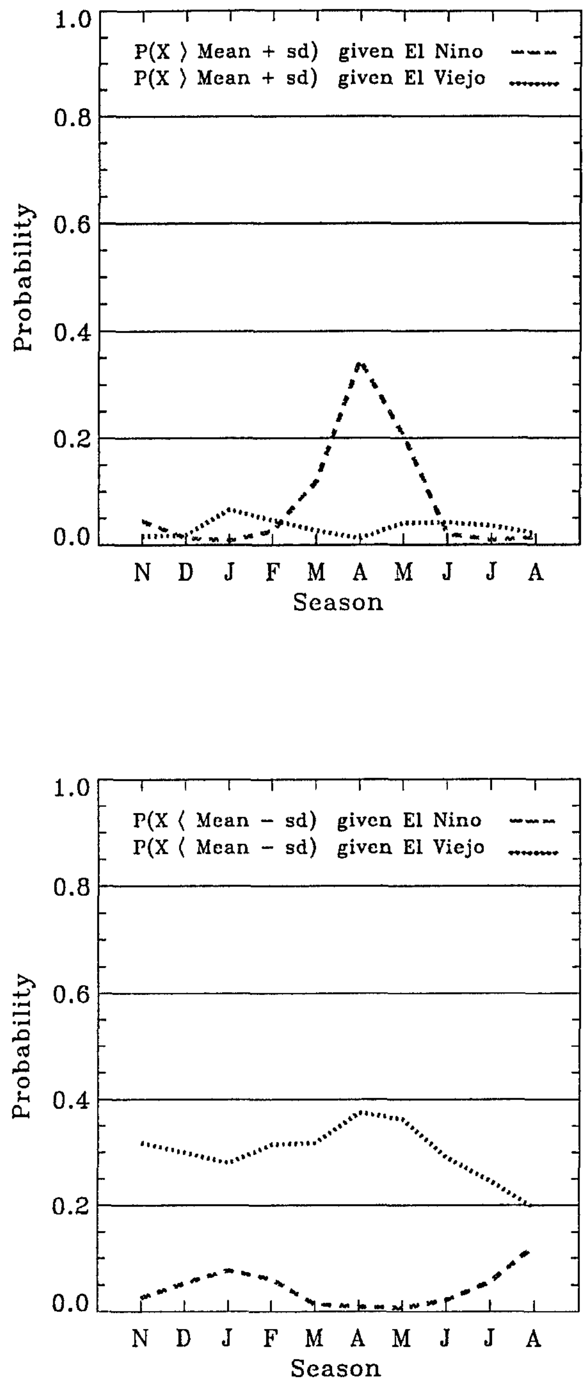


FIG. 8. Conditional probabilities based on resampled data for occurrence of fog at Dover AFB, DE.

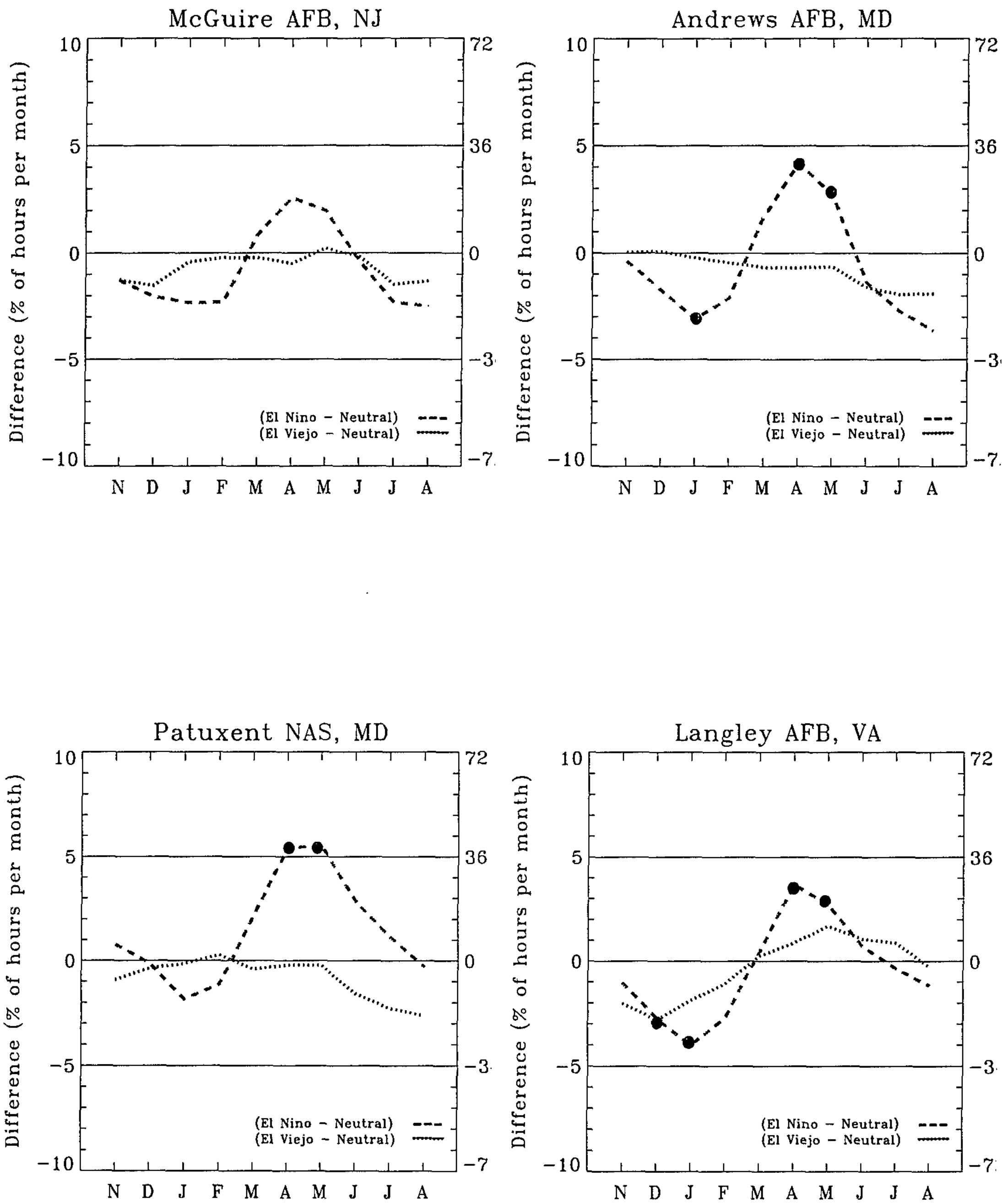


FIG. 9. Difference of means based on resampled data for fog at McGuire AFB, NJ, Andrews AFB, MD, Patuxent River, NAS, MD, and Langley AFB, VA. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Dots mark the seasons with a significant difference based on a two tailed T-test using $\alpha = 0.05$

MD, and Langley AFB, VA all experience less fog in the winter during El Niño years as compared to Neutral years (Fig. 9). In addition, these four locations all experience more fog during the spring of El Niño years than Neutral years. The Gulf Coast stations of Tyndall AFB, FL, Eglin AFB, FL and Keesler AFB, MI all exhibit less fog during El Niño winters (Fig. 10). Two common features are shared by the western stations of Hill AFB, UT, McClellan AFB, CA, Travis, AFB, CA, and Castle AFB, CA. Both El Niño and El Viejo are associated with less fog during the winter, and El Viejo years have even less fog than El Niño years (Fig. 11). These El Viejo year differences of fog occurrence in the west are the greatest fog difference values for the whole country. This 9% difference equates to 64 fewer hours of fog per month during an El Viejo winter. Fairchild AFB, WA, and McChord AFB, WA exhibit a similar but less pronounced pattern with 36 fewer hours of fog in El Viejo winters. Whereas temperature and precipitation often exhibit converse relationships between El Niño and El Viejo (Sittel, 1994), at military stations in the west both El Niño and El Viejo exhibit an identical impact on fog during the winter; a lower frequency of occurrence.

The test of the significance of the differences between the El Niño (El Viejo) mean and Neutral mean produces interesting results (Table 3). Of the 36 stations used in the fog study, only 15 contain seasons with significant differences. McChord AFB, located near Seattle, WA, has significant El Viejo differences for every season, and significant El Niño differences for every season except DJF. At McChord AFB, all differences are less than 36 hours per month (Fig. 2). The 14 other stations have fewer than 5 seasons significant for any one stations. The seasons DJF, JFM, and MAM are significant at the most stations.

The conditional probability results are split for El Niño years; some locations have the probability for more fog, and some less (Table 5). Each station

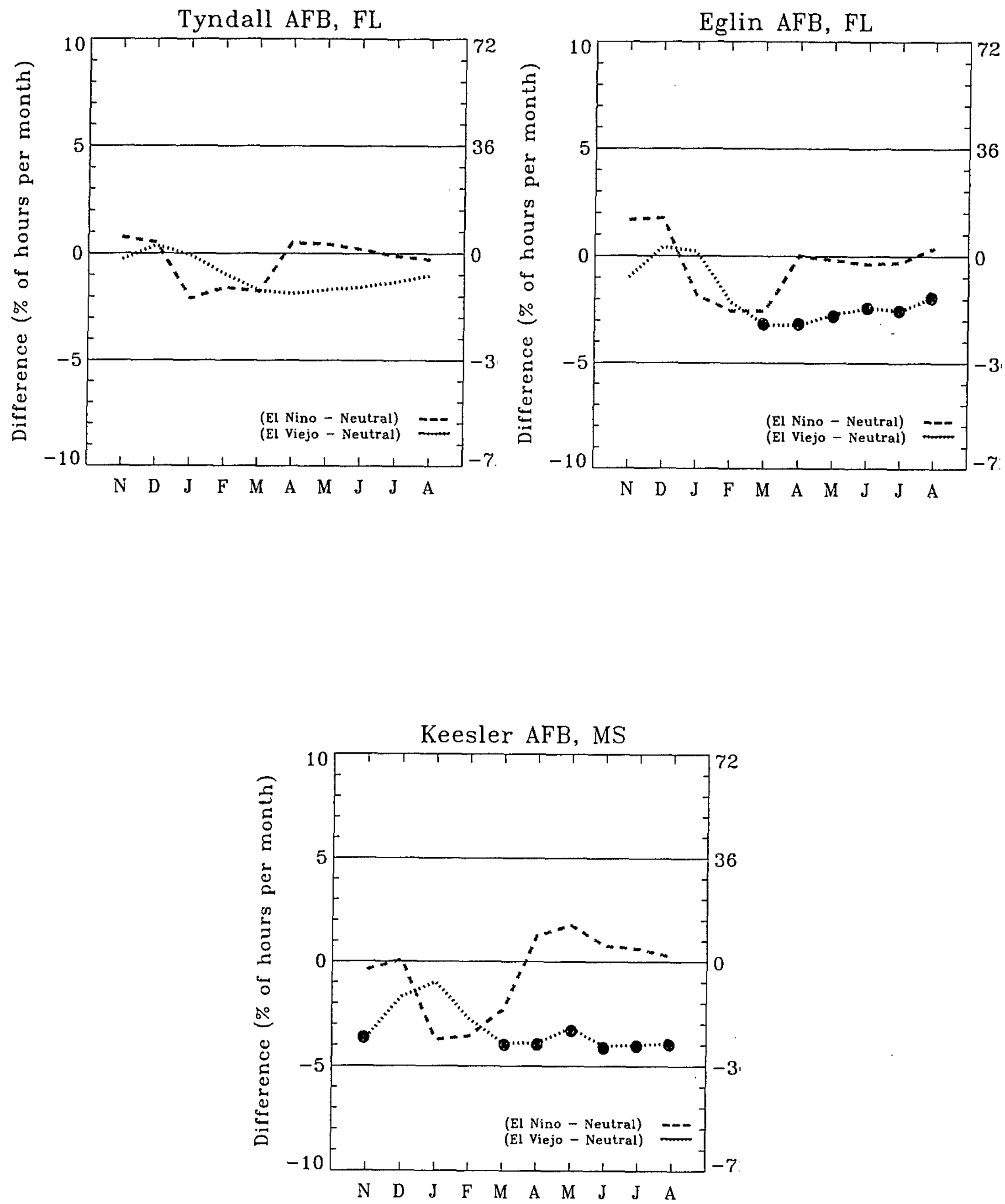


FIG. 10. Difference of means based on resampled data for fog at Tyndall AFB, FL, Eglin AFB, FL, and Keesler AFB, MS. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Dots mark the seasons with a significant difference based on a two tailed T-test using $\alpha = 0.05$

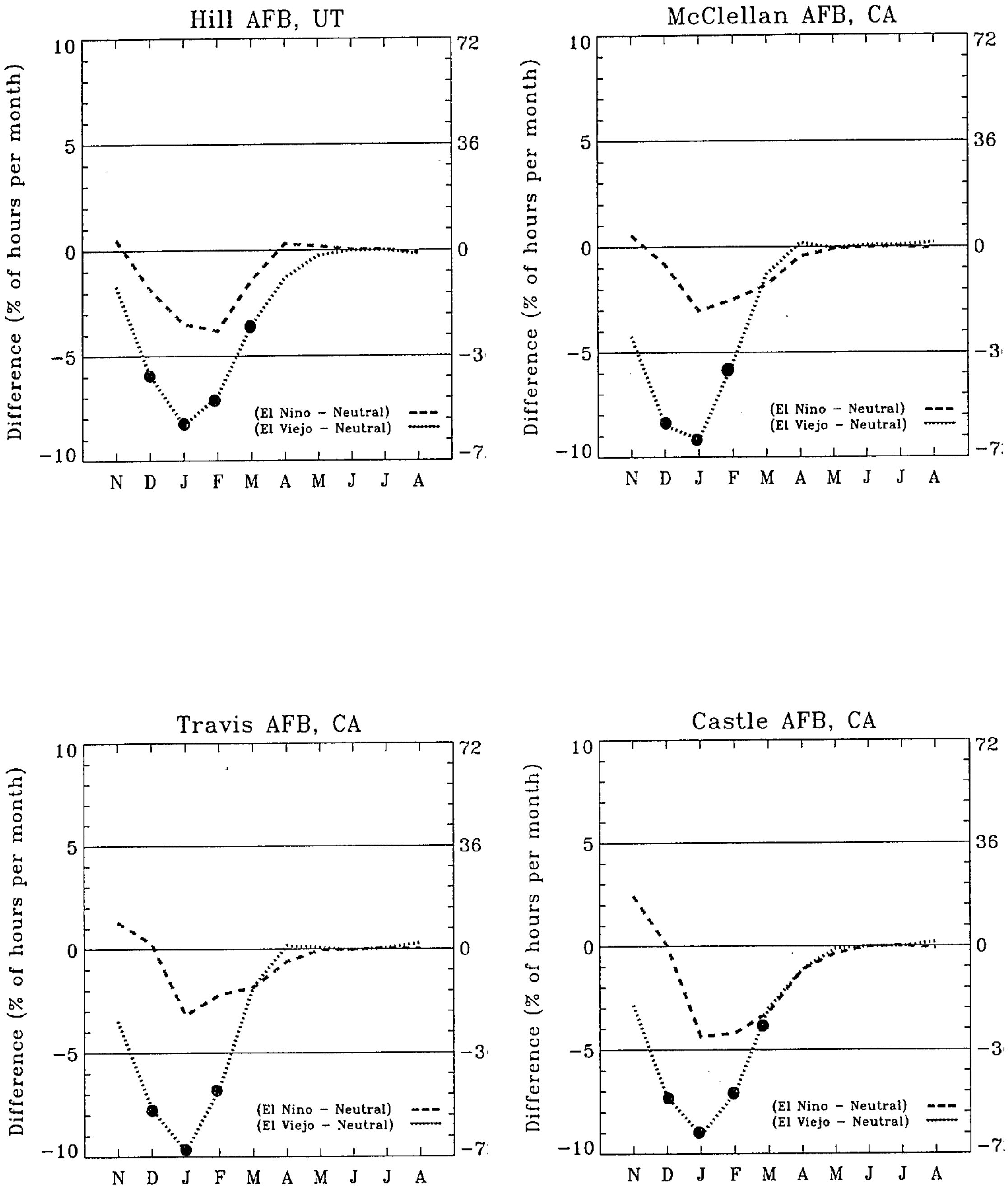


FIG. 11. Difference of means based on resampled data for fog at Hill AFB, UT, McClellan AFB, CA, Travis AFB, CA, Castle AFB, CA. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Dots mark the seasons with a significant difference based on a two tailed T-test using $\alpha = 0.05$

has a unique outlook for El Niño years. For El Viejo however, the results indicate that the majority of stations have a probability greater than 20% for fewer hours of fog. Eilsen AFB, AK, is the only station with more than one season with a probability greater than 20% for more hours of fog.

The formation and duration of fog events is unique to the location and the synoptic situation. Local topography, combined with the wind direction and available moisture are all determining factors. For some locations, like coastal southern California, fog occurs as a diurnal cycle in the marine layer. In other regions, like Texas or the front range of the Rocky Mountains, fog occurs in relation to the topography and wind direction. In still other cases, fog may simply be dependent on a moist boundary layer and clear skies. Although, fog may be a function of local conditions, the general circulation during El Niño and El Viejo certainly has an effect.

El Niño years in the mid-Atlantic region have fewer hours of fog than Neutral years. during the winter A trough in the east associated with the PNA pattern may account for higher winds and less stability which could limit the formation of fog. If the frequency of storms tracking through the region is high during El Niño winters, then the reduced hours of fog may be the result of shorter episodes of fog.

In the southeastern states particularly at military stations located on the Gulf coast, El Niño winters have fewer hours of fog. In this case, increased westerlies in the Gulf of Mexico during El Niño (Ropelewski and Halpert, 1986) may cause the mean wind speed to be too high for the formation of fog in this region, or may cause early dissipation of fog events.

Both El Niño and El Viejo have fewer occurrences of fog at several western locations. The fact that El Viejo differences are more dramatic than El Niño

differences suggest that the factors which control the frequency of fog at these locations are either different for El Niño and El Viejo years or, are much more influential during El Viejo years. During El Niño winters the reduction in fog might be accounted for by a blocking high which ushers low pressure systems further north than usual. Additionally, the surface high often gives rise to a dry offshore flow. El Viejo winters are particularly dry in California (Sittel, 1994b). A trough in the west associated with the "reverse PNA" pattern may allow for frequent airmass changes and shorter lived fog events.

b. IFR Condition

When the cloud ceiling falls below 1000 feet and the visibility is between 1 and 3 miles, Instrument Flight Rules, IFR, go into effect. Under these conditions pilots must fly without visual cues. Therefore, only properly equipped aircraft and instrument rated pilots are allowed to fly. IFR conditions contribute to lost training hours. Although all military aircraft and pilots are equipped to fly in IFR conditions, the risks are too high to practice it on a regular basis. Therefore, training missions and exercises are rarely flown in IFR conditions.

Dobbins Air Force Reserve Base (ARB) GA, is chosen as an example. During the fall, the three ENSO populations closely resemble one another (Fig. 12). The winter season exhibits the most prominent distinction between the El Niño, El Viejo and Neutral populations. The El Niño population during the winter has the smallest mean value and variance. The El Viejo population has the largest mean and the largest variance. The Neutral population falls between the two ENSO extremes (Fig. 12). In the spring and summer IFR conditions do not occur as frequently, and as a result, the three populations are nearly identical and approach an exponential distribution.

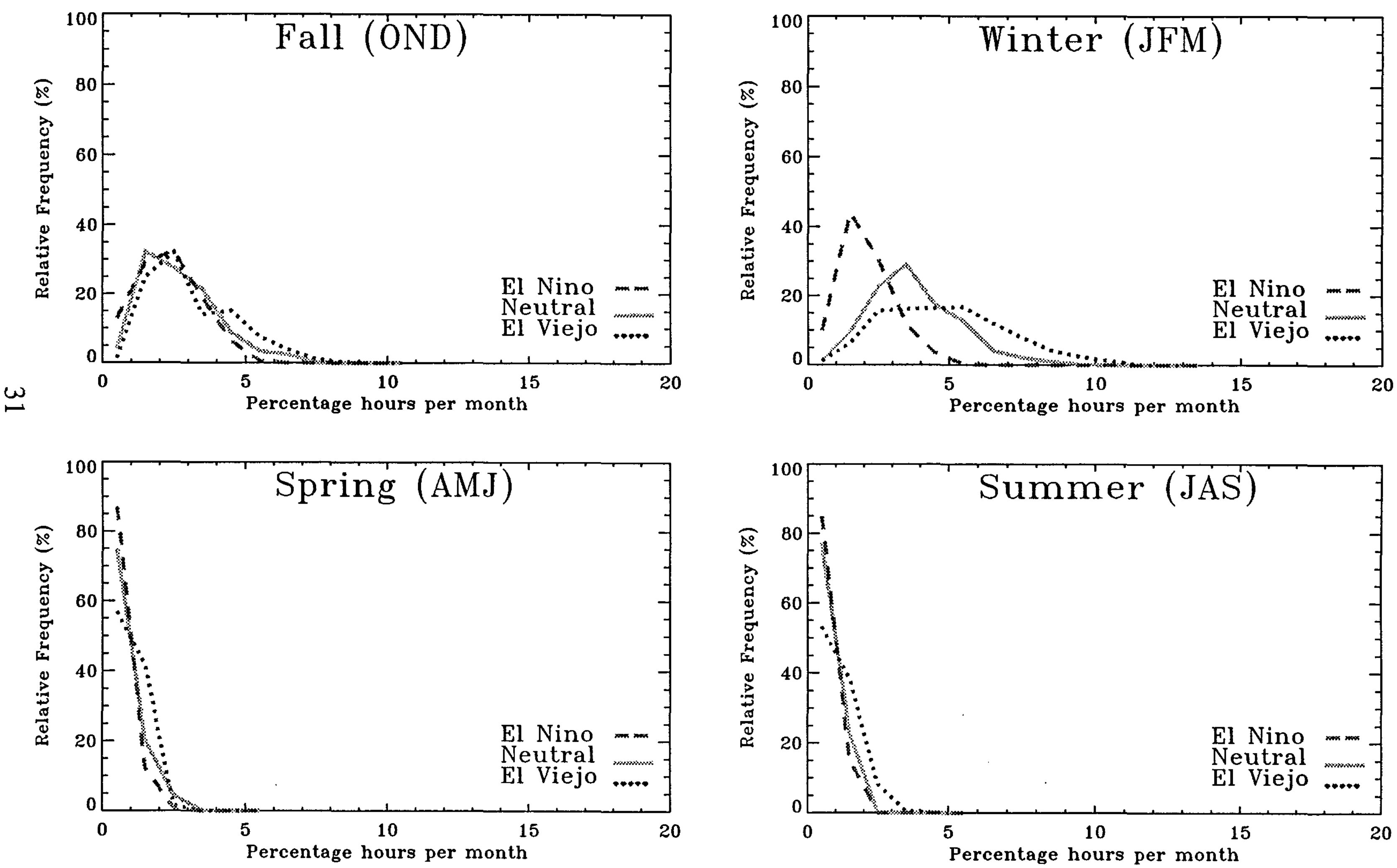


FIG. 12. Histograms of IFR frequency at Dobbins ARB, GA for 4 seasons of the year. Based on resampled historical data for each ENSO category.

Although the difference in the means fluctuate throughout the year, the El Niño year has fewer hours of IFR conditions for every season, and the El Viejo year has more hours for every season (Fig. 13). The greatest differences between the ENSO extremes and the Neutral years occur during the winter. According to the Monte Carlo experiment the El Niño difference for JFM is significant above the 97.5% confidence level (Table 6). Hence, during the JFM season of an El Niño year, approximately 12 fewer hours of IFR conditions can be anticipated per month.

As evident in both the histogram and differences, the winter season displays the most impressive results in the conditional probability analysis. Given that an El Niño year is occurring, Dobbins ARB has a 20-30% probability for fewer hours of IFR conditions from DJF through FMA and MJJ through JJA (Fig. 14b). From the standpoint of operational weather requirements, it can be stated that given an El Niño year during the JFM season, there is a 35% probability for 12 hours or less of IFR conditions per month. For the case of El Viejo years, there is at least a 20% probability for more hours with IFR conditions through the entire year, and a 30-40% probability specifically during the winter (Fig. 14a). Like the previous example for the JFM season, given an El Viejo year there is a 36% probability that over 40 hours of IFR conditions will occur per month. In summary, during the JFM season, the number of flying hours lost due to IFR conditions could be as small as 12 or as large as 40 depending on the ENSO phase.

Among the stations used in the IFR study, there are regional similarities. The trend is fewer IFR hours in the fall and winter of an El Niño year (Table 7). There is a limited number of stations with more IFR hours during an El Niño spring. They are located in the Mid-Atlantic region and include McGuire AFB, NJ, Patuxent NAS, MD, Andrews AFB, MD, and Langley AFB, VA (Fig 15). El Viejo

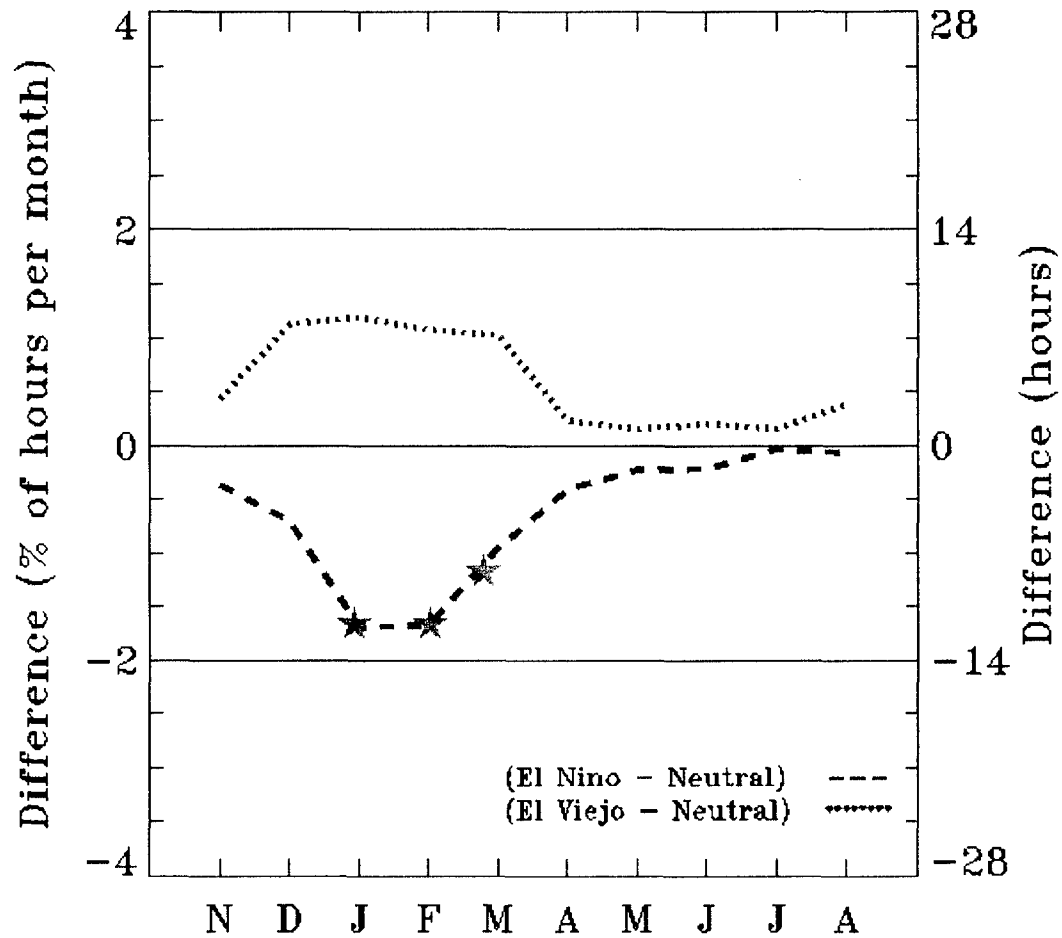


FIG. 13. Difference of means based on resampled data for IFR conditions at Dobbins ARB, GA. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Stars mark the seasons with a significant difference based on a two-tailed T-test using $\alpha = 0.05$.

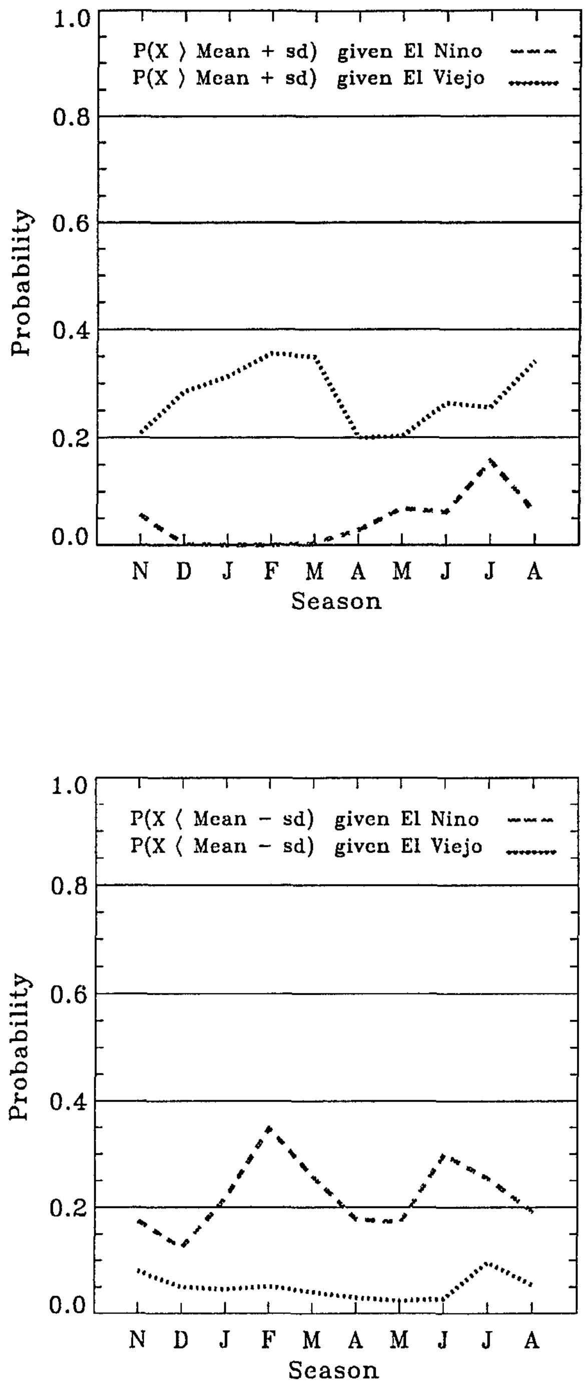


FIG. 14. Conditional probabilities based on resampled data for occurrence of IFR conditions at Dobbins ARB, GA.

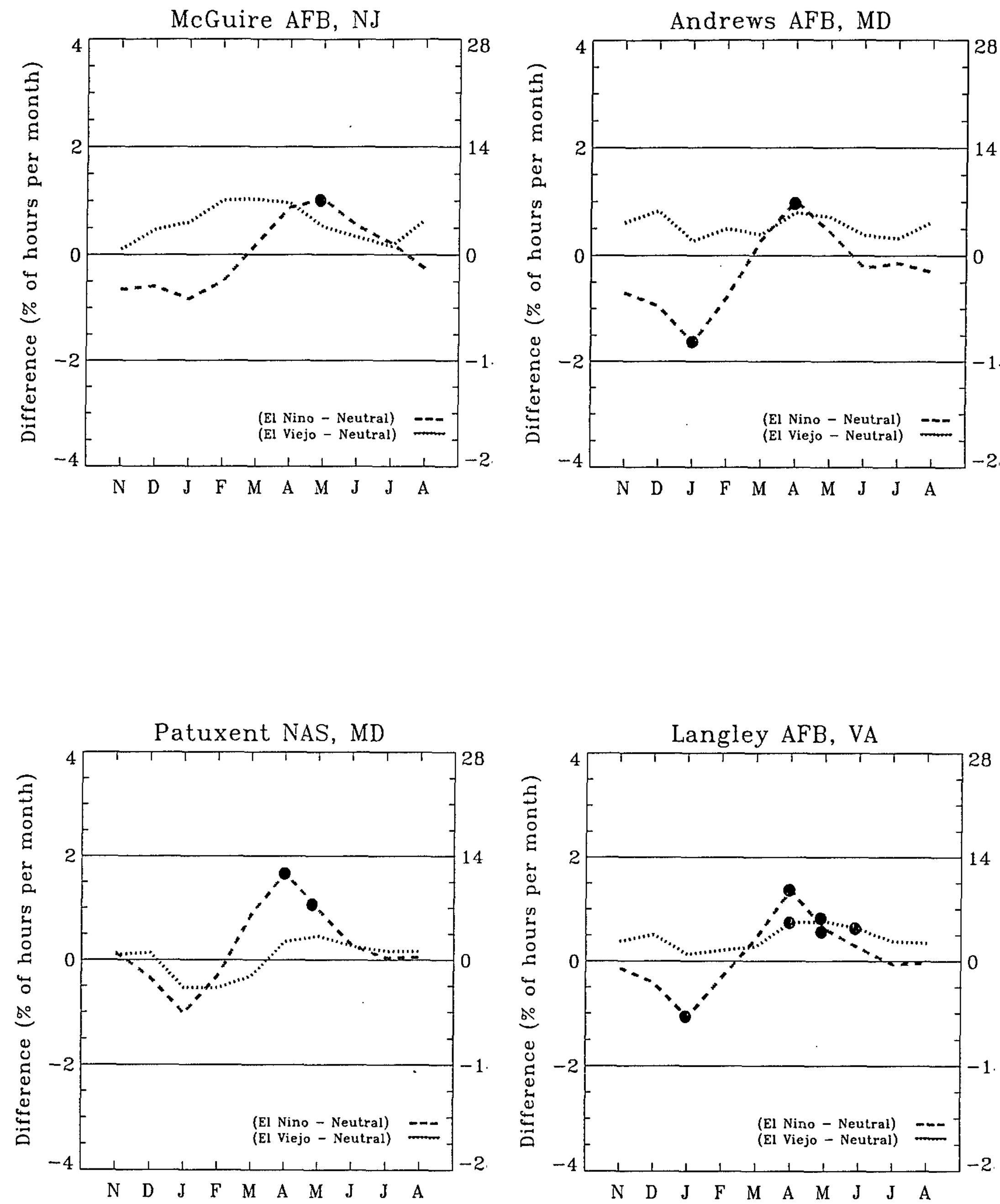


FIG. 15. Difference of means based on resampled data for IFR conditions at McGuire AFB, NJ, Andrews AFB, MD, Patuxent NAS, MD, Langley AFB, VA. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Dots mark the seasons with a significant difference based on a two tailed T-test using $\alpha = 0.05$

results are dependent upon location. Generally, the stations with fewer IFR hours are located in the west. During an El Viejo winter, at Cannon AFB, NM, Fairchild AFB, WA, Hill AFB, UT, McClellan AFB, CA, and Travis AFB, CA, there are fewer IFR hours than Neutral winters (Fig. 16).

The El Niño differences which are significant at the 97.5% confidence level occur primarily in the fall and winter. Conversely, the El Viejo differences tend to be significant in the spring and summer even though the differences are smaller and represent fewer hours during these seasons (Table 6). The season JFM has a significant impact at the most stations.

For many of the stations in the continental United States there is a greater than 20% probability for more IFR hours in an El Viejo year and fewer hours of IFR conditions in an El Niño year (Table 8). There are seasons at many bases which are exceptions. However, only two stations, Cannon AFB, NM, and Offutt AFB, NE, have opposite probabilities of more IFR hours during El Niño and fewer during El Viejo.

Low stratus cloud decks and fog often comprise IFR conditions. These conditions typically occur in regions where warm moist air is forced over cold air, like the overrunning zone along a warm front. Occasionally thick fogs that lift only a few hundred feet off the ground constitute an IFR condition. Restrictions to visibility such as heavy precipitation, blowing snow etc. can also be involved in an IFR event.

IFR conditions are more effected by the large scale circulations than fog. Yarnal and Diaz (1986) conclude that precipitation anomalies associated with the PNA and "reverse PNA" patterns are sensitive to the precise arrangement of the longwaves. It is possible that like precipitation, IFR conditions are sensitive to the exact alignment of the ridge and trough in the large scale circulations.

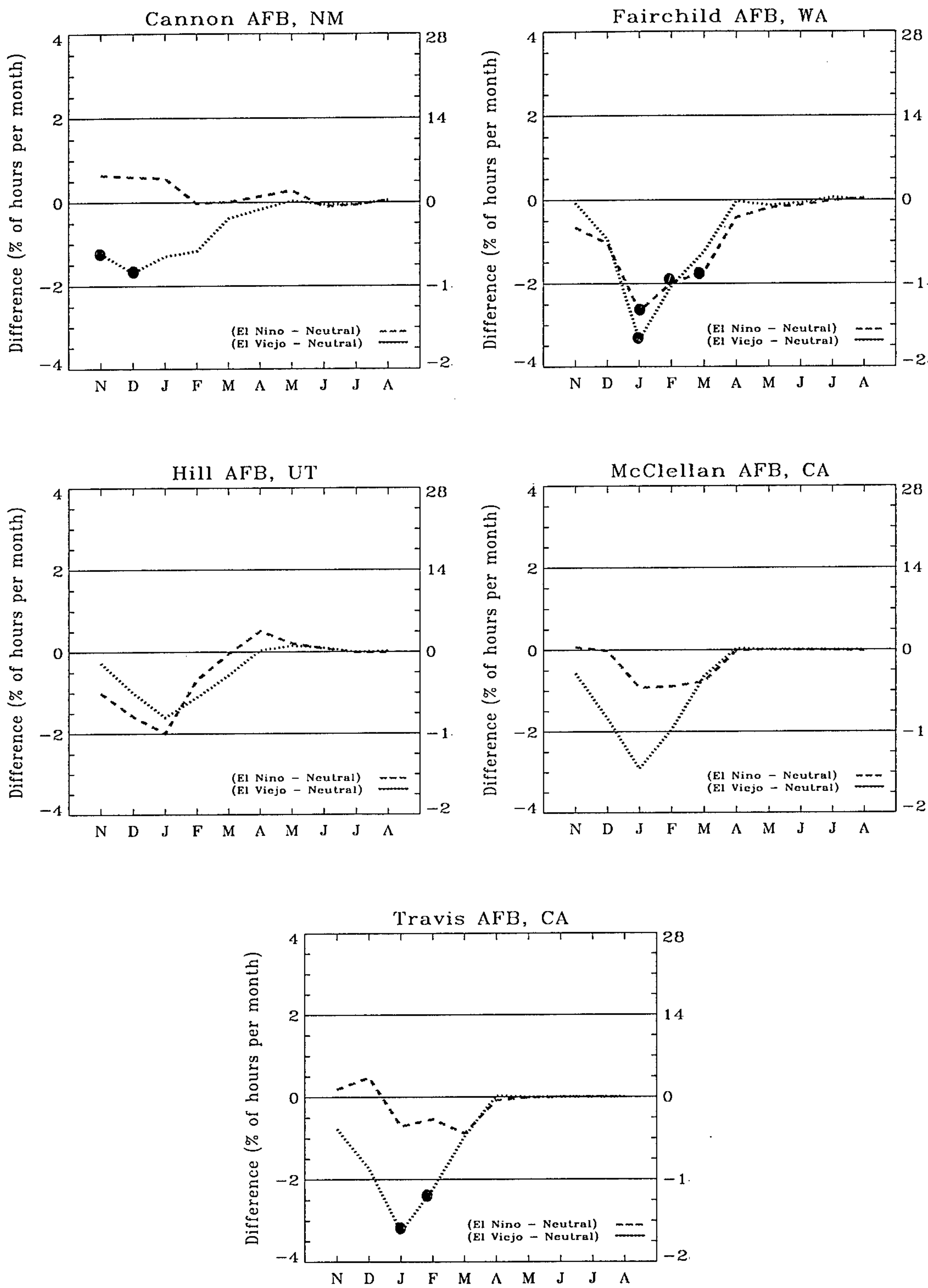


FIG. 16. Difference of means based on resampled data for IFR conditions at Cannon AFB, NM, Fairchild AFB, WA, Hill AFB, UT, McClellan AFB, CA, and Travis AFB, CA. (See Fig. 15)

In the mid-Atlantic region an increase in IFR hours during an El Niño spring may be the result of an increased flow of warm, moist air from the southeast overrunning shallow pockets of cold air at the surface as winter transitions to spring. During an El Viejo year in the west, fewer IFR hours are likely due to the mean position of the trough associated with the "reverse-PNA". Low stratus clouds will not occur west of the trough, therefore, if the trough is located inland, the coastal regions may remain relatively clear. Additionally, the west is colder than normal during El Viejo winters as a result of the trough allowing polar air to flow into the western U.S.. Continental cold dry air is not a favorable ingredient for stratus. Similarly the position of the trough could cut-off the west from a maritime flow from the Pacific. Conversely, El Viejo years in the eastern U.S., have more IFR hours. The "reverse-PNA" ridge in the east may allow flow from the Gulf of Mexico into the east. The position of the surface high is also critical in pulling warm moist air from the Gulf into the Great Plains or southeastern states.

c. Snow

Unlike the previous climate variables, snow presents a hazard to more than just flying operations. The safety of daily operations becomes a primary issue when snow begins to fall. Non-essential personnel are released early if heavy snow is forecasted. Snow removal equipment is brought out to maintain the flight line and roadways. Back-up generators are brought on-line to insure that no loss of power occurs.

Wright Patterson AFB, OH is chosen to represent the snow results for two reasons. Snow is a common occurrence in Ohio, and this base employs the largest number of military and civilian personnel in the Air Force (USAF Almanac, 1996). Snow does not fall as regularly in the fall as in the winter. Therefore, the three ENSO populations display more distinct characteristics in the winter (Fig. 17).

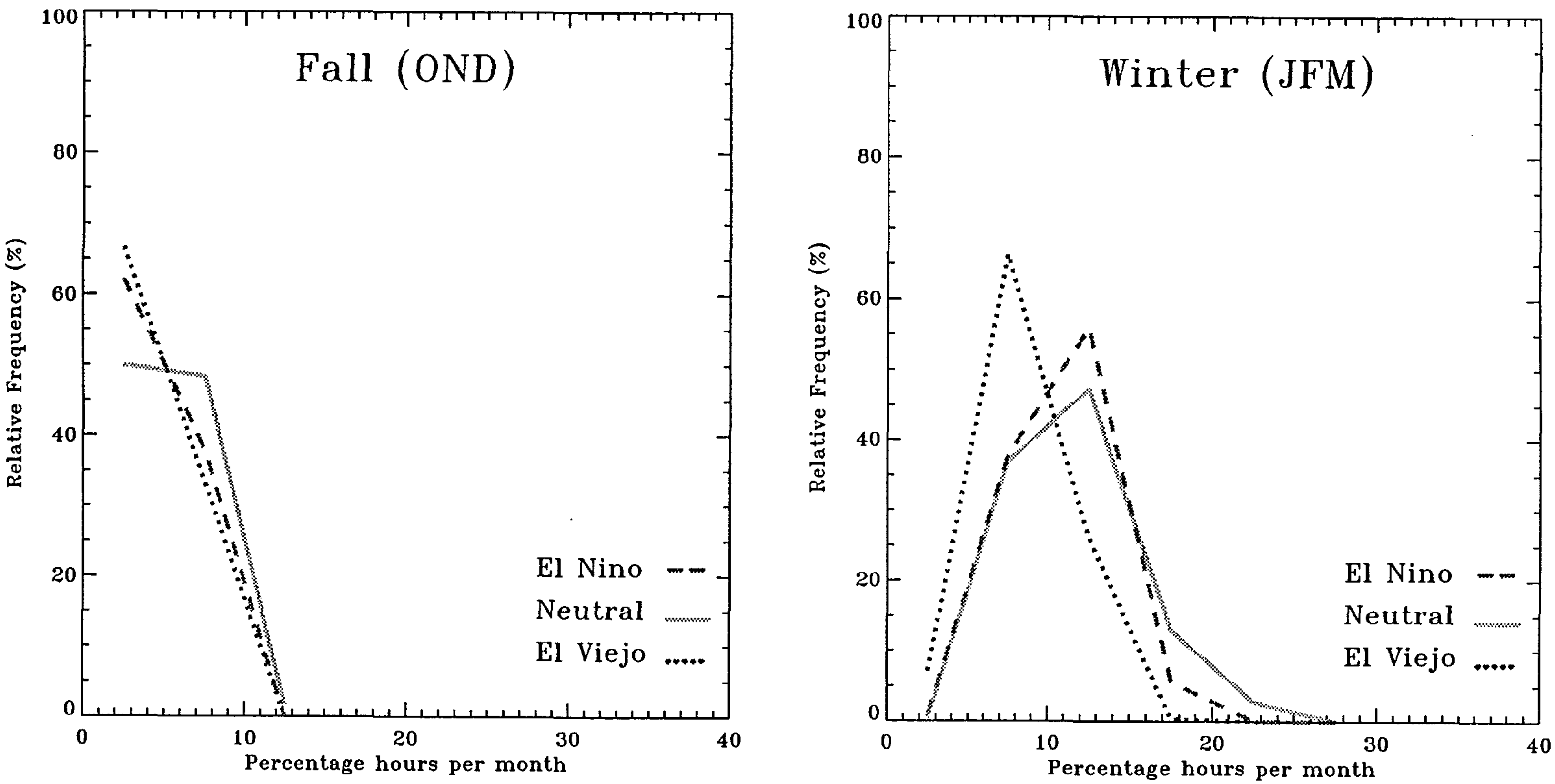


FIG. 17. Histograms of snow at Wright Patterson AFB, OH for 2 seasons of the year. Based on resampled historical data for each ENSO category.

The El Viejo population has the smallest mean value and variance, the Neutral population has the largest mean and variance and the El Niño population mean and variance lies between the prior two (Fig. 17).

Both the El Niño and El Viejo means for all seasons are less than the Neutral means (Fig. 18). The maximum difference occurs in the DJF season for both ENSO extremes. The El Viejo years have 35 fewer hours of snowfall per month than Neutral years. The El Niño difference represents 13 fewer hours of snowfall per month. The El Viejo differences for the three seasons NDJ, DJF, and JFM are all significant at greater than the 97.5% confidence level (Table 9).

A clear relationship between snow occurrences and El Niño is not apparent from the conditional probability analysis for Wright Patterson AFB, OH (Fig. 19). For example, during the NDJ season the probability of more snow is 11% and the probability of less snow is also 11%. Conversely, knowing that a given year is an El Viejo, the probability is greater than 20% for all seasons that less snowfall will occur, and the probabilities of more snow are smaller than 7%. Specifically, during the DJF season of an El Viejo year there is a 31% probability for fewer than 53 hours of snowfall per month. This is 20 fewer hours than an average year.

El Viejo winters are both warmer and wetter than Neutral winters in Ohio. The 'reverse PNA' pattern is described by a ridge of high pressure over the eastern US which allows for anomalously high temperatures across the region. This is true for the southwestern corner of Ohio. During El Viejo winters there is a swath of positive precipitation anomalies to the west of the Appalachians (Sittel, 1994b). This could be the result of moisture from the Gulf of Mexico being funneled up the back side of the high pressure system. Although there is

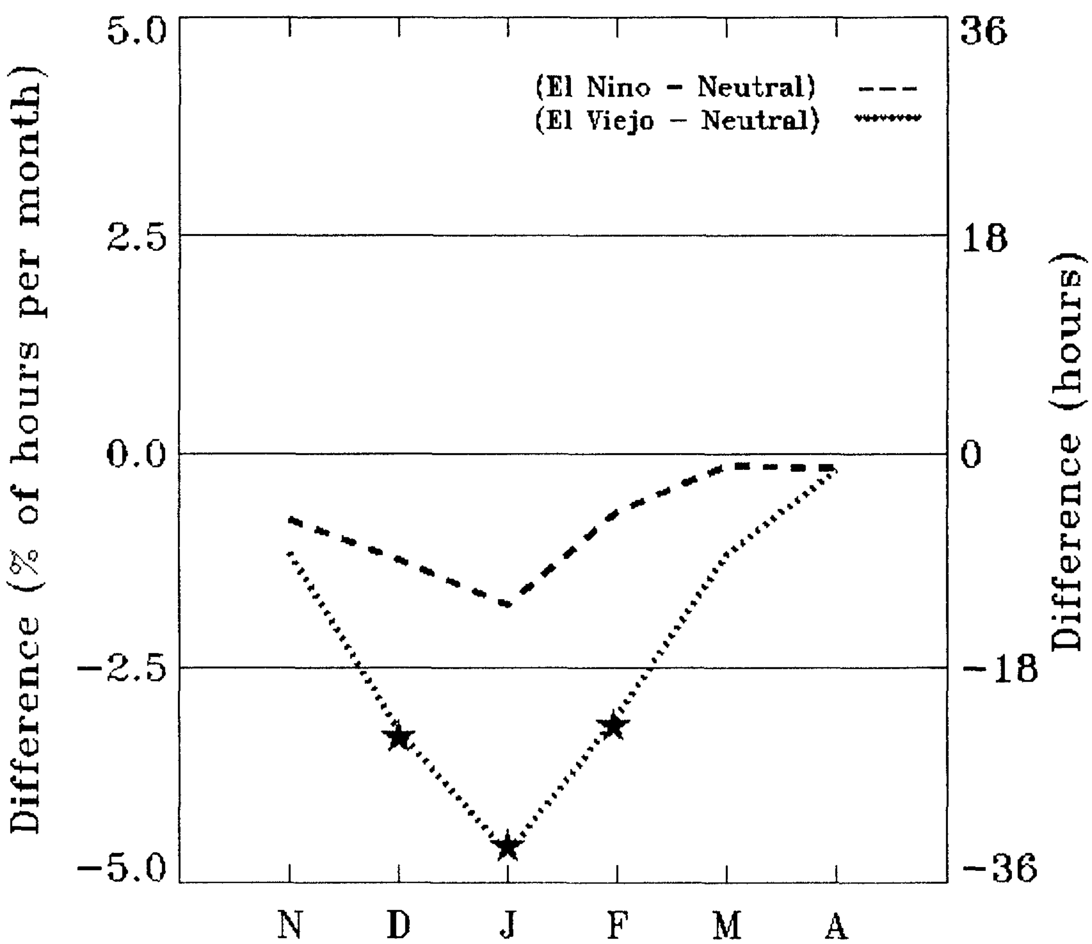
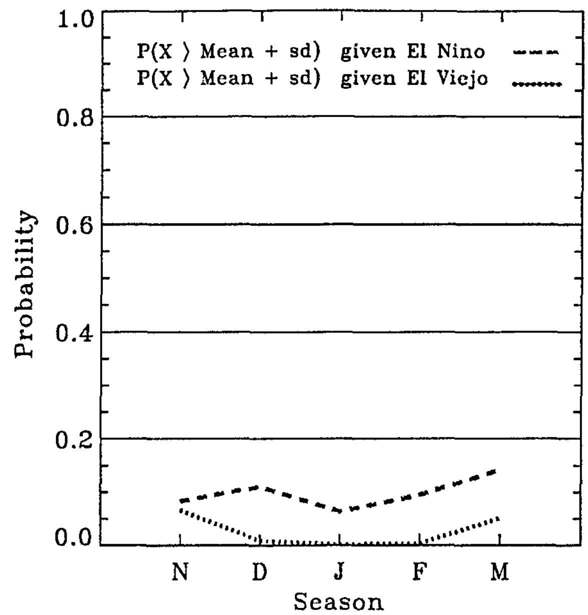


FIG 18. Difference of means based on resampled data for snow at Wright Patterson AFB, OH. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Stars mark the seasons with a significant difference based on a two-tailed T-test using $\alpha = 0.05$.



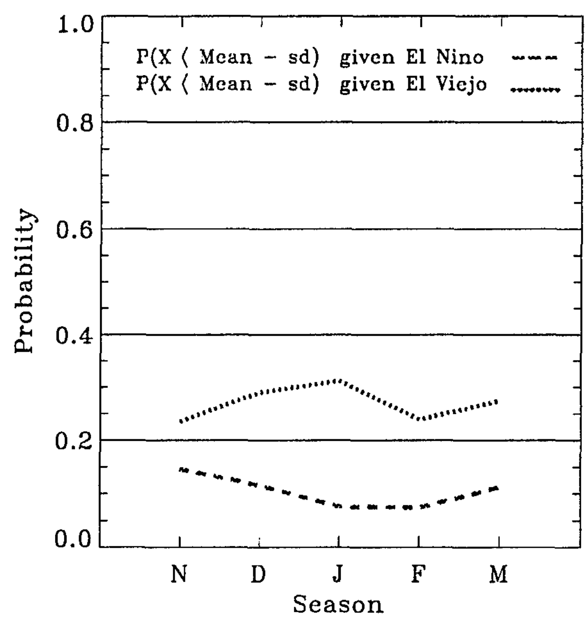


FIG. 19. Conditional probabilities based on resampled data for occurrences of snow at Wright Patterson AFB, OH.

more available moisture during El Viejo winters, it is more likely to fall in the form of rain than snow.

From a regional perspective, both El Niño and El Viejo years exhibit fewer hours of snowfall than Neutral years. The exceptions are Eilsen AFB, AK, Elmendorf AFB, AK, Fairchild AFB, WA, and Hill AFB, UT, where El Viejo years have more snowfall than Neutral years (Table 10). Only Elmendorf AFB, AK, and F.E. Warren AFB, WY have seasons with more snowfall during El Niño years. Only four stations have significant differences (Table 9). The DJF season is significant at the most locations.

The conditional probability analysis indicates that twelve stations should expect more snow during El Niño years and twelve stations have a probability greater than 20% for less snow during an El Niño year (Table 11). F.E. Warren AFB, WY has probabilities for both more snow and less snow during an El Niño year depending on the season (Fig. 20). The impact of El Niño on snowfall at stations east of the Mississippi River is ambiguous. For example, at Dover AFB, DE the conditional probability results suggest that, given an El Niño year there is a 13% probability that fewer hours of snow will occur. The results also suggest there is a 13% probability that more hours of snow will occur. The conditional probabilities paint a much clearer picture for El Niño in the west (Fig. 20). At the southwest station of Cannon AFB, NM, given an El Niño year the probability is greater than 20% that more hours of snow will occur. Given an El Viejo year, the majority of stations have a probability for fewer hours of snow, with the exception of stations located in the northwest which can expect more hours of snow (Table 11).

As opposed to El Niño, El Viejo has an unequivocal impact on snow. The eastern ridge of the 'reverse PNA' pattern promotes higher temperatures during

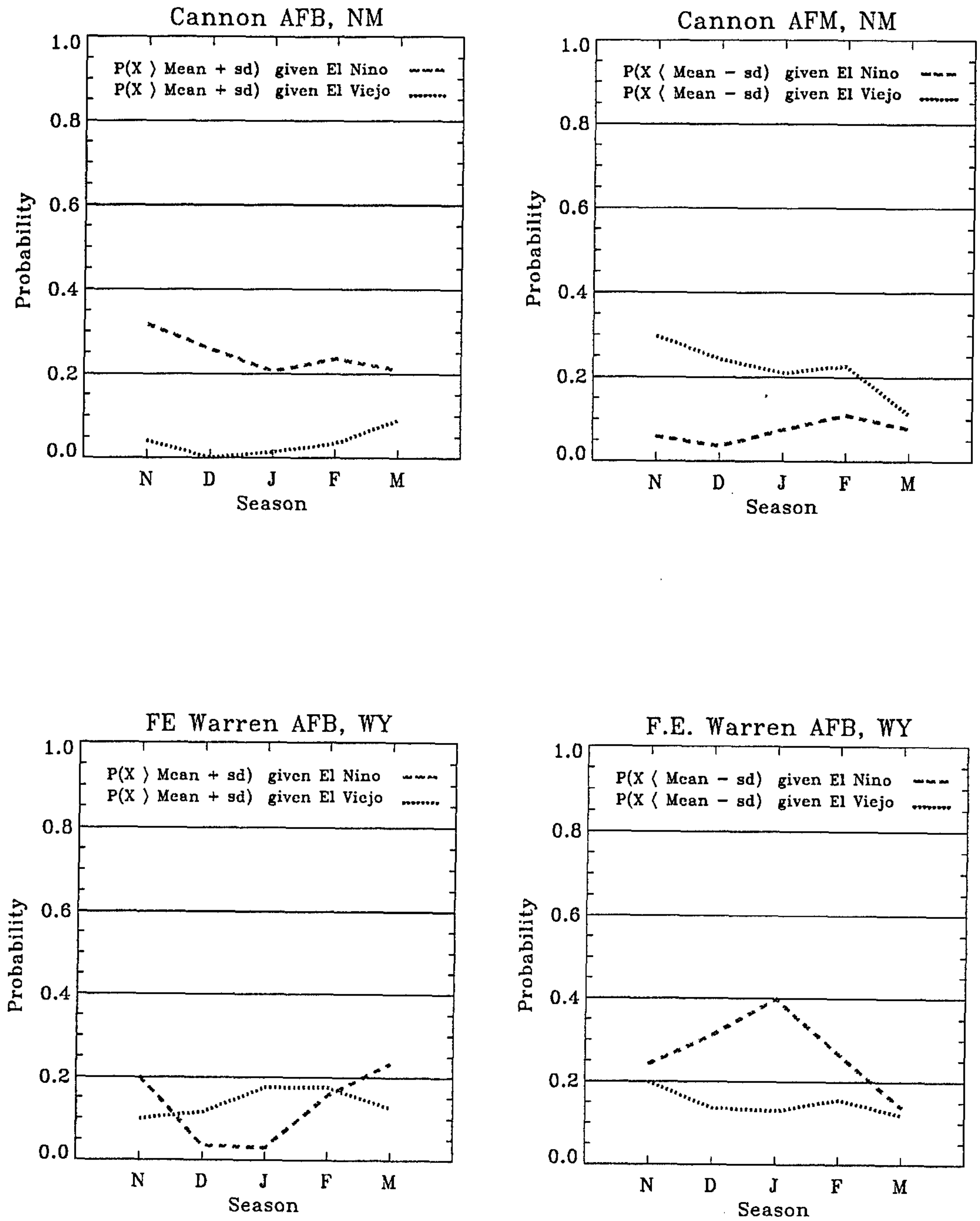


FIG. 20. Conditional probabilities based on resampled data for occurrences of snow at Cannon AFB, NM and F.E. Warren AFB, WY.

El Viejo winters throughout the eastern US. The ridge also accounts for drier conditions in the southeast and along the Atlantic coast (Sittel, 1994b). The precipitation anomalies along the back side of the high, coincide with the positive temperature anomalies which are not conducive to snow, as in the previous example for Wright Patterson AFB, OH. The Pacific northwest is the only location with high probabilities for increased snow during El Viejo winters. The 'reverse-PNA' pattern produces will below normal temperatures along the west coast of the U.S. and Canada (Yarnal and Diaz, 1986). According the Sittel (1994b), positive precipitation anomalies in this region can be as large a seven centimeters per month during El Viejo winters. Consequently, in the Pacific northwest, the ingredients are available for more snow to occur during El Viejo winters, which agrees with the results from the statistical analyses.

d. Freezing Rain

Freezing rain is the weather condition which is most dangerous to military operations of the climate variables studied here. Fortunately, it is also the least common. Aircraft which fly through freezing rain experience clear icing, an accumulation of ice along the wings and fuselage. Freezing rain not only makes runway conditions dangerous, but it also makes roadway conditions hazardous for military personnel. It is a threat to the maintenance of power and communications systems around the base, as well as to the safety of military personnel.

The ingredients for freezing rain; precipitation falling through a warm pocket aloft into cold air at the surface are so specific, that it is a rare form of precipitation. This is evident in the positively skewed histograms of fall and winter at Tinker AFB, OK (Fig. 21). The population means are such that the El Niño mean is the smallest, the Neutral mean is slightly larger, and the El Viejo

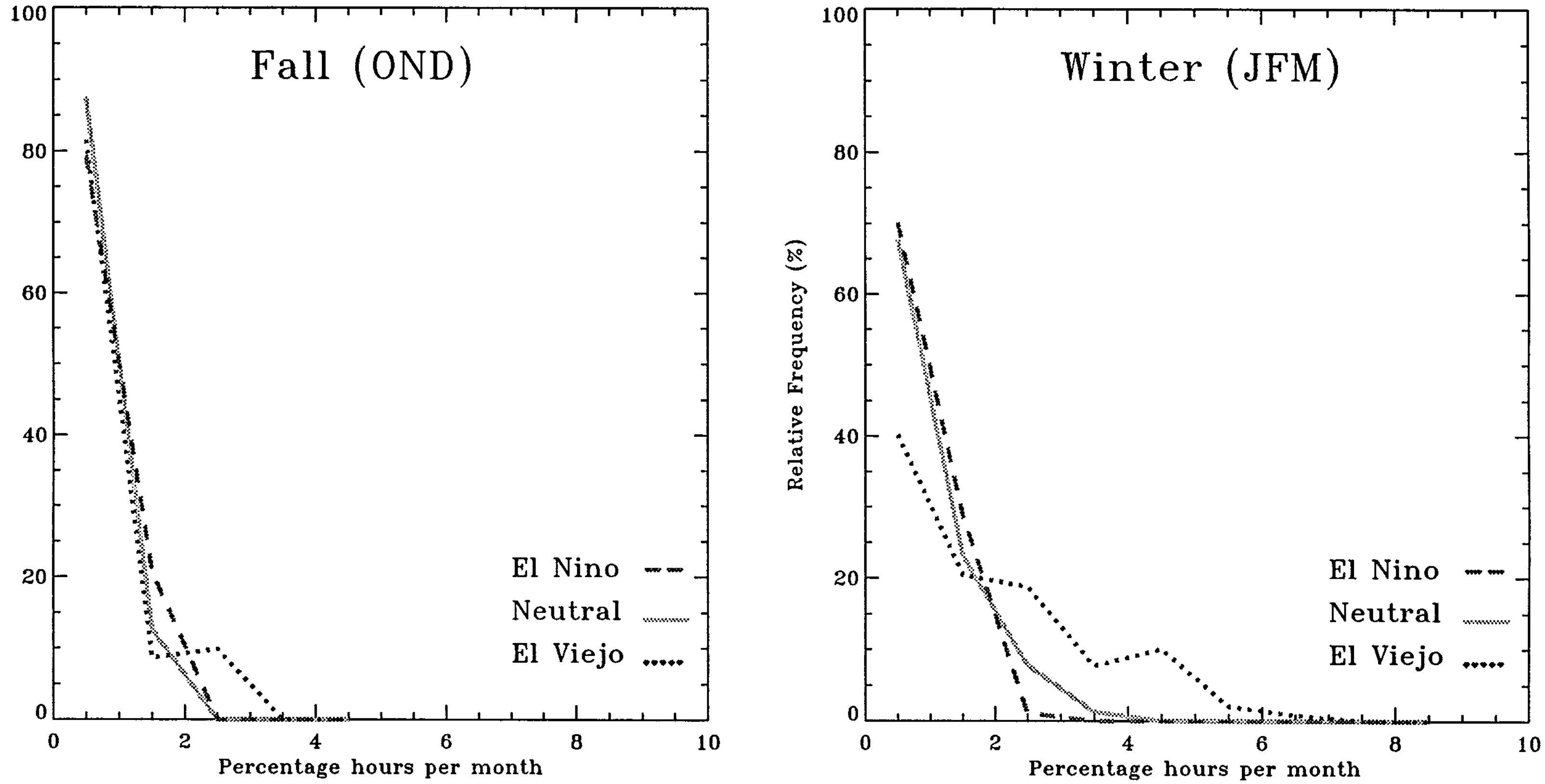


FIG. 21. Histograms of freezing rain at Tinker AFB, OK for 2 seasons of the year. Based on resampled historical data for each ENSO category.

mean is the largest. This is true for all of the stations except Fairchild AFB, WA, Ft. Sill, OK, Reese AFB, TX and Elmendorf AFB, AK. At Tinker AFB, the difference in mean hours of freezing rain per month between El Niño years and Neutral years is less than 1.5 hours for all seasons. In contrast, for El Viejo years the mean number of hours exceeds Neutral years by approximately 7 hours for the winter seasons of DJF and JFM (Fig. 22).

The differences between the El Niño means and Neutral year means are less than 0.4%, or approximately three hours, for every station except Offutt AFB, NE where six fewer hours occur during the DJF season. This season, in addition to JFM and FMA, has a significant difference between the El Niño mean and Neutral mean at Offutt AFB (Table 12). Although, the El Niño differences are small, in most cases El Niño years have fewer hours of freezing rain than Neutral years. The El Viejo differences are larger than the El Niño differences, but still less than 1%; approximately 7 1/2 hours. Unlike El Niño, El Viejo years have more hours of freezing rain than Neutral years. The differences with the largest magnitude occur at Tinker AFB. Four stations have significant differences with the highest occurrence in the FMA season (Table 12).

The conditional probability analysis for freezing rain was unsuccessful for all but 13% of the curves which were fit to the Weibull distribution. In many cases only the El Viejo curves for particular stations could be fit to the Weibull distribution. For instance, the JFM season at Offutt AFB, NE had a good fit for El Viejo, but not El Niño. As a result there is a 24% probability for at least 11 hours of freezing rain per month at Offutt AFB. Likewise, Scott AFB, IL, El Viejo curves fit in DJF and JFM which leads to the conditional probability of 20% and 27% respectively for more freezing rain and only 2% probability of fewer hours in both seasons. Griffiss AFB, NY is the only station with good fits for both El Niño

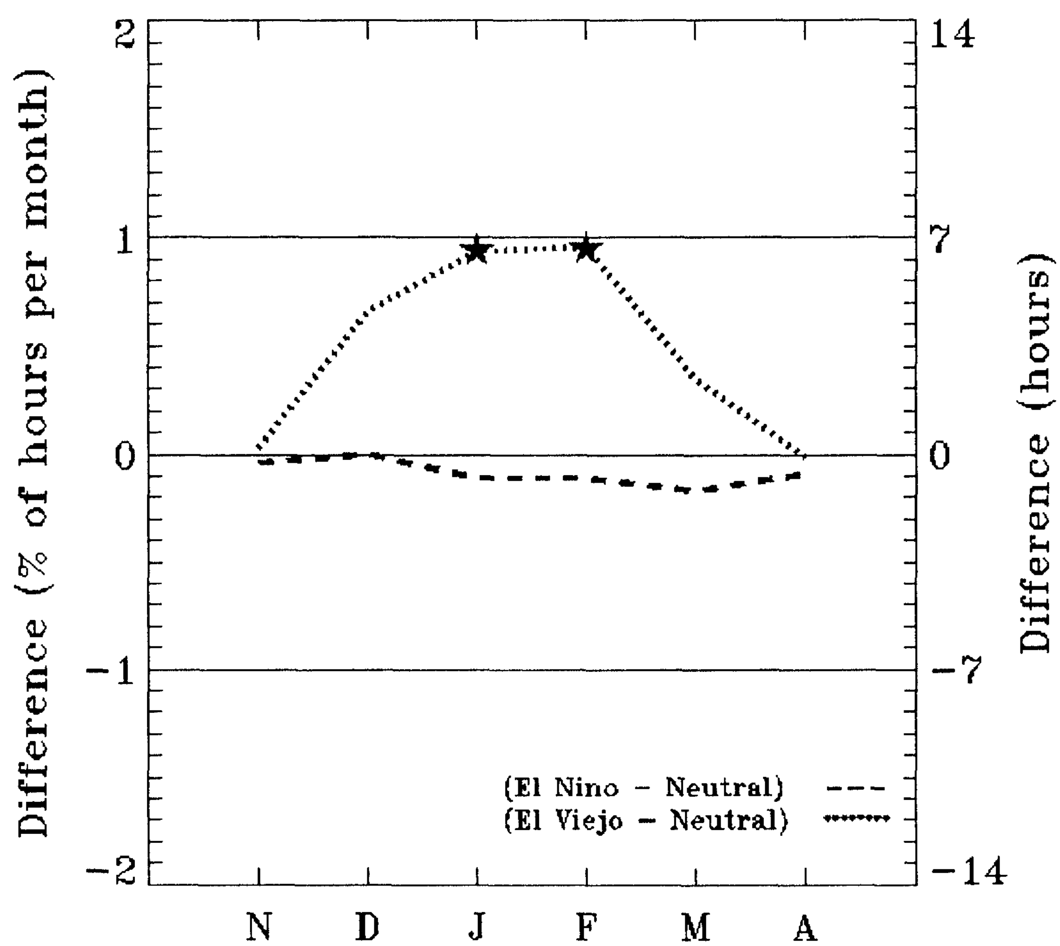


FIG. 22. Difference of means based on resampled data for freezing rain at Tinker AFB, OK. Center month of three month season along abscissa. Percentage difference along left ordinate axis. Approximate hourly difference along right ordinate axis. Stars mark the seasons with a significant difference based on a two-tailed T-test using $\alpha = 0.05$.

and El Viejo (Fig. 23). The three seasons NDJ, DJF, and JFM all show that given an El Niño year, less freezing rain is probable, and given an El Viejo year, more freezing rain is probable by 30%. During the DJF season there is a 33% probability that at least 15 hours of freezing rain will occur given an El Viejo year, and there is a 26% probability that fewer than 4 hours will occur given an El Niño year.

The greatest response to ENSO for freezing rain occurs during El Viejo years in a region from Nebraska to Oklahoma. Freezing rain is likely to occur north of a warm front during the winter. In the overrunning region, precipitation falling from the warm air aloft into the shallow wedge of cold air preceding the warm front could become freezing rain provided that the surface conditions are below freezing. Supposing that El Viejo years are characterized by the "reverse PNA" pattern with a trough in the west and ridge in the east, then the mid-West is in an ideal region for freezing rain potential based on storms tracking across the region.

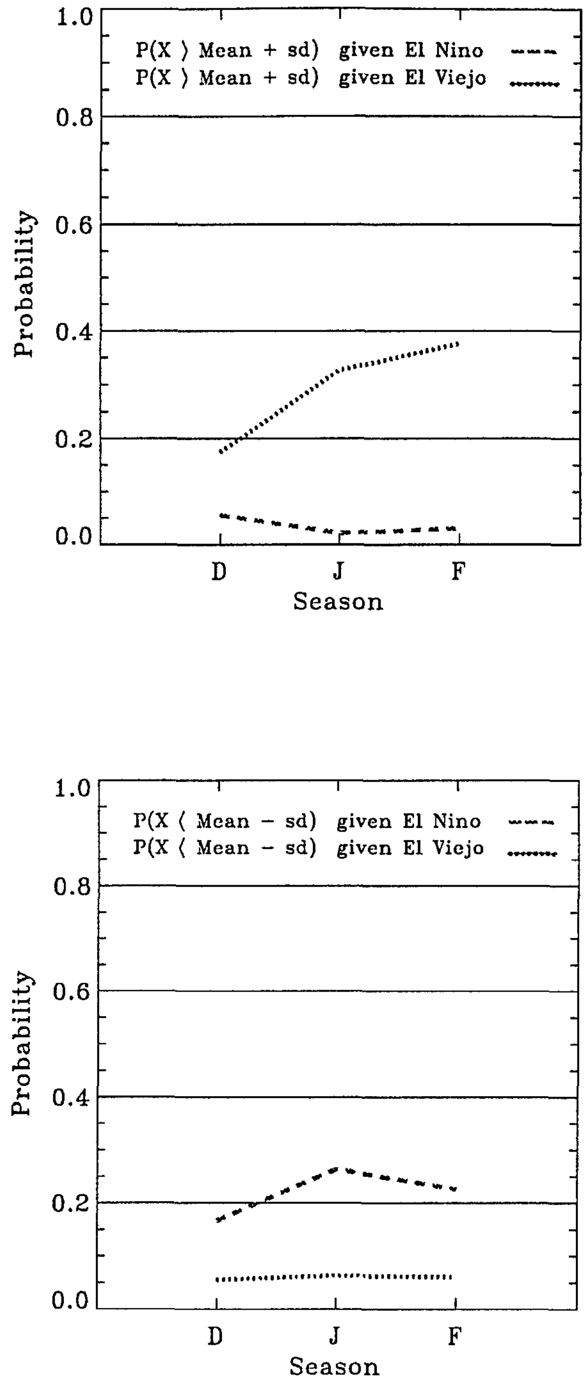


FIG. 23. Conditional probabilities based on resampled data for occurrences of freezing rain at Griffiss AFB, NY.

5. CONCLUSIONS

This study presents a statistical relationship between the extremes of ENSO for four climate variables; fog, IFR, snow, and freezing rain, at military bases in the continental United States.

For all four climate variables, El Viejo plays a significant role. For each climate variable, the magnitude of the El Viejo differences are greater than the El Niño differences during more seasons. Additionally, El Viejo years have more seasons with a probability greater than 20% for significantly more (or less) fog, IFR, and freezing rain. Therefore, the cold phase of ENSO should not be overlooked in the study of climate variability.

Generally both El Niño years and El Viejo years have fewer hours of fog than Neutral years. A few stations in the mid-Atlantic region experience more fog, in the spring of an El Niño year and Eilsen AFB, AK experiences more fog during an El Viejo winter. The probability of a particular military station having fewer or more hours of fog during an El Niño year is unique for each base and season and does not follow a regional pattern. During an El Viejo year, however, fewer hours of fog are probable everywhere except in the northwest.

The El Niño IFR results roughly mirror the fog results with the majority of military stations having fewer hours of IFR conditions in the fall and winter, and the mid-Atlantic stations experience more IFR hours in the spring. Given an El Viejo year the stations in the west generally have fewer hours of IFR and stations in the east have more hours. For most locations fewer hours of IFR are

probable during an El Niño year, although there are a few exceptions which have a probability greater than 20% for more IFR during the spring. The probabilities are overwhelmingly in favor of more IFR hours during El Viejo years across most of the country.

Snow, like fog, is less frequent in both El Niño and El Viejo years than Neutral years. During an El Viejo year the probability is greater than 20% for fewer hours of snow everywhere except the northwest. The probability of either more or less snow during an El Niño year is unique to each base and season.

El Viejo years experience more freezing rain events in general for the entire country. The ENSO extremes have the most definitive influence on freezing rain in the mid-West, particularly Nebraska, Oklahoma and Illinois. For this region the highest probabilities are for more freezing rain hours given an El Viejo year.

The big picture

The results of this study align with the ENSO influenced areas identified by previous authors such as the Gulf Coast, Southeast and Northwestern tier (Barnston et al., 1994), coastal Virginia and Maryland (Ropelewski and Halpert, 1995), and Alaska (Ropelewski and Halpert, 1986). Many of the results are consistent with the Pacific North American (PNA) pattern or the "reverse-PNA". The spatial coverage of military bases across the continental United States is thin, thus the effects of large scale circulation patterns are not always apparent from the results. The exact configuration of the PNA pattern varies with each ENSO (Ropelewski and Halpert, 1986). Therefore by replicating this study with more stations and over a longer time period, to encompass more ENSO events, an enhanced regional pattern may become apparent. A more in-depth study of the

synoptic scale circulations accompanying ENSO events is necessary to substantiate this project.

The results challenge the common paradigm that El Niño and El Viejo will have opposing effects on climate. Although, El Niño and El Viejo represent opposite thermal conditions in the equatorial Pacific, the atmosphere's response is more complex. For many cases, such as fog and snow, both El Niño and El Viejo show a similar trend of a reduced number of hours per month. In these cases, it would be worthwhile to investigate the climate variable further and determine what physical processes effect it. Then it may become clear how El Niño effects the region as opposed to El Viejo.

b. The little picture

It is convenient to make broad sweeping conclusions relating ENSO to particular climate variables, but often, the physical processes which effect particular variables are local, such as in the formation of fog or freezing rain. Synoptic scale atmospheric circulations which are altered by ENSO, generate regional changes in wind direction, temperature and moisture advection. These changes in turn effect the local climate uniquely at each military base. Based on the results, less fog is probable during an El Niño year, but to understand fully requires more knowledge about the characteristics of the fog. For instance, is the fog at this location mostly radiation fog, advection fog or upslope fog? Does it occur at the same time everyday? Are the changes in the amount of fog due to variations in wind direction, cloud cover, or whether or not it rained the previous day? To build an accurate picture of the climate at a particular location the statistics alone are not enough. It is advantageous to also understand the local climate and physical process which occur frequently. This is an avenue for further study.

c. What's the value of these results?

In an age when the American public has asked the military to run a tighter ship, it behooves the efficiency-minded military planners to take climate variability into account. Every piece of information in the climate puzzle is valuable in building the big picture. For example, in assessing jet fuel requirements for the upcoming fiscal year, it is useful to know the probability of fewer flying hours due to inclement conditions in the winter based on the fact that it is an El Viejo year. By the same token, it is also useful to know that during the summer of that same year, the number of hours of fog or IFR conditions will not differ significantly from climatology. The role of ENSO can be clearly defined by examining all of the results together. For example at Wright Patterson AFB, OH, an upcoming El Niño year indicates that fewer hours of fog, snow and IFR conditions are probable. Similarly, Elmendorf AFB, AK, has its own unique climate. Given an El Viejo year less fog is probable as is more snow and IFR conditions. Hence, for the military, knowledge of climate variability is power in making better informed decisions.

APPENDIX

Table 1. Summary of military bases. The climate variables studied for each location are shaded.

Station	Latitude (°N)	Longitude (°W)	Fog	IFR	Snow	Freezing rain
Andrews AFB, MD	38.82	76.87				
Barksdale AFB, LA	32.50	93.67				
Bergstrom ARS, TX	30.20	97.68				
Cannon AFB, NM	34.38	103.32				
Castle AFB, CA	37.38	120.57				
Dobbins ARB, GA	33.92	84.52				
Dover AFB, DE	39.13	75.47				
Eglin AFB, FL	30.48	86.53				
Eilsen AFB, AK	64.82	147.87				
Ellesworth AFB, SD	44.05	103.07				
Elmendorf AFB, AK	61.25	149.80				
England AFB, LA	31.33	92.55				
Fairchild AFB, WA	47.62	117.65				
FEWarren AFB, WY	41.15	104.82				
Ft Benning, GA	32.33	85.00				
Ft Knox, KY	37.90	85.97				
Ft Sill, OK	34.65	98.40				
Ft Worth MEAC, TX	32.82	97.35				
Griffiss AFB, NY	43.23	75.40				
Hill AFB, UT	41.12	111.97				
Hunter AAF, GA	32.02	81.15				
Keesler AFB, MS	30.42	88.92				
Kelly AFB, TX	29.38	98.58				

Table 1. Continued

Station	Latitude (°N)	Longitude (°W)	Fog	IFR	Snow	Freezing rain
Langley AFB, VA	37.08	76.37				
MacDill AFB, FL	27.85	82.52				
Malmstrom AFB, MT	47.50	111.18				
March AFB, CA	33.88	117.27				
Maxwell AFB, AL	32.38	86.37				
McChord AFB, WA	47.15	122.48				
McClellan AFB, CA	38.67	121.40				
McGuire AFB, NJ	40.02	74.60				
Moody AFB, GA	30.97	83.20				
North Island NAS, CA	32.70	117.20				
Offut AFB, NE	41.12	95.92				
Patuxent River NAS, MD	38.28	76.40				
Pope AFB, NC	35.17	79.02				
Randolph AFB, TX	29.53	98.28				
Reese AFB, TX	33.60	102.05				
Robbins AFB, GA	32.70	83.65				
Scott AFB, IL	38.55	89.85				
Shaw AFB, SC	33.97	80.47				
Tinker AFB, OK	35.42	97.38				
Travis AFB, CA	38.70	121.60				
Tyndall AFB, FL	30.07	85.58				
Vance AFB, OK	36.33	97.92				
Wright Patterson AFB, OH	39.83	84.05				

Table 2. Classification of years 1947-1992 according to the JMA/SST index. (1948 represents October 1948 through September 1949)

El Niño	Neutral	El Viejo
1951	1950	1947
1957	1952	1948
1963	1953	1949
1965	1958	1954
1969	1959	1955
1972	1960	1956
1976	1961	1964
1982	1962	1967
1986	1966	1970
1987	1968	1971
1991	1974	1973
	1977	1975
	1978	1988
	1979	
	1980	
	1981	
	1983	
	1984	
	1985	
	1989	
	1990	
	1992	

Table 3. Significance test results for fog. Seasons during which the El Niño (El Viejo) differences are significant above the 97.5% confidence level are shaded. Hatched represents El Niño difference, stipled represents El Viejo difference, and dark hatch represents when both El Niño and El Viejo difference are significant for the particular season. Only stations with significant seasons are included.

Station	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS
Andrews AFB, MD										
Bergstrom ARS, TX										
Dobbins ARB, GA										
Dover AFB, DE										
Eglin AFB, FL										
Eilsen AFB, AK										
Fairchild AFB, WA										
Hill AFB, UT										
Langley AFB, VA										
McChord AFB, WA										
North Island NAS, CA										
Offutt AFB, NE										
Scott AFB, IL										
Travis AFB, CA										
WrightPattersonAFB,OH										
El Niño difference										
El Viejo difference										
Both										

Table 4. Difference results for fog. Each entry indicates the season, by 3 letter abbreviation in which the El Niño (El Viejo) mean exceeds the Neutral mean by at least 2% (more fog) or the El Niño (El Viejo) mean is less than the Neutral mean by at least 2% (less fog). Stations with differences between 0 and 2% are not included in the table. A dash indicates all seasons between listed seasons are included.

Stations	El Niño		El Viejo	
	Less fog	More fog	Less fog	More fog
Andrews AFB, MD	DJF,JFM,JJA,JAS	MAM,AMJ		
Barksdale AFB, LA		OND	OND,NDJ,AMJ	
Bergstrom ARS, TX			OND,NDJ,DJF	
Castle AFB, CA	DJF,JFM,FMA	OND	OND-FMA	
Dobbins ARB, GA	DJF,JFM			NDJ
Dover AFB, DE	NDJ-JFM,JJA,JAS	MAM,AMJ	OND,NDJ,DJF,JAS	
Eglin AFB, FL	JFM,FMA		JFM-JJA	
Eilsen AFB, AK	OND-FMA			OND-JFM
Elmendorf AFB, AK	DJF,JFM			
Fairchild AFB, WA	JFM,FMA		NDJ,DJF,JFM	
Ft Benning, GA		MJJ,JJA	DJF,AMJ-JAS	
Ft Knox, KY			OND,NDJ,MAM,JAS	
Ft Sill, OK			OND	
Ft Worth MEAC, TX		OND,NDJ,DJF	OND	
Griffiss AFB, NY	JJA,JAS		DJF,JFM,FMA,JJA	
Hill AFB, UT	DJF,JFM		NDJ,DJF,JFM,FMA	
Hunter AAF, GA			OND,NDJ,JAS	
Keesler AFB, MS	DJF,JFM,FMA		OND,JFM-JAS	
Kelly AFB, TX		AMJ	OND	
Langley AFB, VA	NDJ-JFM,MAM,AMJ		OND,NDJ	
Malmstrom AFB, MT	DJF		FMA	
March AFB, CA	JFM		MAM,AMJ	
McChord AFB, WA	JAS	OND,NDJ	OND,NDJ,DJF,JFM	JAS
McClellan AFB, CA	DJF,JFM		OND,NDJ,DJF,JFM	

Table 4. Continued

Stations	El Niño		El Viejo	
	Less fog	More fog	Less fog	More fog
McGuire AFB, NJ	NDJ-JFM,JJA,JAS	MAM		
North IslandNAS,CA	OND,NDJ,DJF,JFM			
Offut AFB, NE	JFM,FMA,MAM,MJJ	OND	JFM-MJJ	
Patuxent R. NAS, MD		FMA-MJJ	JJA,JAS	
Pope AFB, NC			JJA,JAS	
Scott AFB, IL	DJF,JFM,MAM-MJJ		OND-JAS	
Shaw AFB, SC	DJF		OND	
Tinker AFB, OK			OND,MAM	
Travis AFB, CA	DJF,JFM		OND,NDJ,DJF,JFM	
Tyndall AFB, FL	DJF			
WrightPat.AFB, OH	DJF,JFM,FMA		NDJ-JJA	

Table 5. Conditional probability results for fog. Each entry is the season, indicated by 3 letter code, in which the probability exceeds 20%. No probabilities exceed 50%. Stations with probabilities less than 20% are not included. Less fog signifies the probablility that the mean value for the indicated season and ENSO category is less than the mean minus one standard deviation of all years. More fog signifies the probability that the mean value for the indicated season and category is greater than the mean plus one standard deviation of all years.

Station	El Niño		El Viejo	
	Less fog	More fog	Less fog	More fog
Andrews AFB, MD	DJF,JFM,JAS	FMA,AMJ	MAM,AMJ	DJF
Barksdale AFB, LA			NDJ-MAM,JJA-JAS	
Bergstrom ARS, TX		OND,AMJ,MJJ	OND,NDJ,DJF	
Castle AFB, CA			NDJ,DJF,JFM,FMA	
Dover AFB, DE		MAM,AMJ	OND-JJA	
Eglin AFB, FL	DJF, JFM,FMA	OND,NDJ	JFM-MJJ	
Eilsen AFB, AK	OND-JFM	MAM		OND-DJF,FMA
Elmendorf AFB, AK	OND, NDJ,DJF		NDJ,JFM-MAM,JJA JAS	MAM
Fairchild AFB, WA	AMJ,MJJ	OND	DJF,JFM	MAM
Ft Benning, GA			DFJ,JFM,MAM	
Ft Knox, KY			FMA,MAM	
Ft Sill, OK			NDJ,FMA	
Ft Worth MEAC, TX		OND,NDJ		
Griffiss AFB, NY			NDJ,JFM	
Hill AFB, UT		MAM,AMJ	MAM	
Hunter AAF, GA			OND-FMA,JJA	
Kelly AFB, TX		OND,NDJ,MAM-MJJ	OND,NDJ	
Langley AFB, VA	DJF,JFM	MAM,AMJ		
Malmstrom AFB, MT				OND
March AFB, CA	DJF,JFM			

Table 5. Continued

Station	El Niño		El Viejo	
	Less fog	More fog	Less fog	More fog
McChord AFB, WA			NDJ,OND,DJF,JFM	JAS
McClellan AFB, CA			NDJ,DJF,JFM,FMA	
McGuire AFB, NJ	DJF	MAM	FMA,MAM,AMJ	
North IslandNAS,CA	DJF, JFM,FMA			
Offut AFB, NE	MJJ	OND,NDJ	FMA-MJJ	
Patuxent R. NAS, MD		MAM,AMJ,MJJ	DJF,JFM,FMA,MAM	
Scott AFB, IL			JFM	
Tinker AFB, OK			NDJ,FMA,JAS	JAS
Travis AFB, CA			NDJ-MAM	MAM
Tyndall AFB, FL		OND		
Wright Pat AFB, OH			MAM,AMJ,MJJ	

Table 6. Significance test results for IFR conditions. Seasons during which the El Niño (El Viejo) differences are significant above the 97.5% confidence level are shaded. Hatched represents El Niño difference, stipled represents El Viejo difference, and dark hatch represents when both El Niño and El Viejo difference are significant for the particular season. Only stations with significant seasons are included.

Station	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS
Andrews AFB, MD										
Barksdale AFB, LA										
Dobbins ARB, GA										
Dover AFB, DE										
Eilsen AFB, AK										
Fairchild AFB, WA										
Ft. Knox, KY										
Langley AFB, VA										
McChord AFB, WA										
Moody AFB, GA										
North Island NAS, CA										
Patuxent River NAS,MD										
Reese AFB, TX										
Scott AFB, IL										
Tinker AFB, OK										
Travis AFB, CA										
Wright Pat. AFB, OH										
El Niño difference										
El Viejo difference										

Table 7. Difference results for IFR conditions. Each entry indicates the season, by 3 letter abbreviation in which the El Niño (El Viejo) mean exceeds the Neutral mean by at least 1% (more IFR) or the El Niño (El Viejo) mean is less than the Neutral mean by at least 1% (less IFR). Stations with differences between 0 and 1% are not included in the table.

Stations	El Niño		El Viejo	
	Less IFR	MoreIFR	Less IFR	MoreIFR
Andrews AFB, MD	DJF	MAM		
Barksdale AFB, LA				NDJ,DJF,JFM
Bergstrom AFB, TX	NDJ,DJF			
Cannon AFB, NM			OND,DJF,JFM	
Dobbins AFB, GA	DFJ,JFM			NDJ,DJF,JFM,FMA
Dover AFB, DE	DJF			
Eglin AFB, FL	JFM,FMA			NDF,DJF
England AFB, LA	OND,NDJ,DJF			
Fairchild AFB, WA	NDJ,DJF,JFM,FMA		DJF,JFM,FMA	
Ft. Knox, KY	DJF,JFM			
Ft. Sill, OK				DJF,JFM,FMA
Hill AFB, UT	OND,NDJ,DJF		NDJ,DJF,JFM	
Keesler AFB, MS	DJF,JFM,FMA			NDJ,DJF,JFM
Kelly AFB, TX	DJF			
Langley AFB, VA	DJF	MAM		
March AFB, CA				DJF
McChord AFB, WA	DJF,JFM			
McClellan AFB, CA			NDJ,DJF,JFM	
McGuire AFB, NJ		AMJ		JFM,FMA
North Island NAS, CA	OND,NDJ,DJF,JFM			JFM
Patuxent R. NAS, MD	DJF	MAM		
Randolph AFB, TX			OND	
Reese AFB, TS			OND,NDJ	
Scott AFB, IL	DJF,JFM			

Table 7. Continued

Stations	El Niño		El Viejo	
	Less IFR	MoreIFR	Less IFR	MoreIFR
Tinker AFB, OK				NDJ,DJF,FMA
Travis AFB, CA			NDJ,DJF,JFM	
Wright Pat.AFB, OH	DJF,JFM			

Table 8. Conditional probability results for the IFR climate variable. Each entry is the season, indicated by 3 letter code, in which the probability exceeds 20%. No probabilities exceed 50%. Stations with probabilities less than 20% are not included. Less IFR signifies the probablility that the mean value for the indicated season and ENSO category is less than the mean minus one standard deviation of all years. More IFR signifies the probability that the mean value for the indicated season and category is greater than the mean plus one standard deviation of all years. A dash indicates all seasons between listed seasons are included.

Station	El Niño		El Viejo	
	Less IFR	More IFR	Less IFR	More IFR
Andrews AFB, MD	OND-JFM,JJA,JAS	MAM		OND-JFM,AMJ-JAS
Barksdale AFB, LA	OND			OND-AMJ,JAS
Bergstrom AFS, TX	NDJ		OND,NDJ	DJF-FMA
Cannon AFB, NM		OND-DJF,AMJ	OND-DJF	
Dobbins ARB, GA	JFM-FMA,MJJ,JJA			OND-FMA,AMJ-JAS
Dover AFB, DE	JFM		OND	
Eglin AFB, FL	JFM-FMA	OND		OND-JFM,JJA,JAS
Eilsen AFB, AK				OND
Ellesworth AFB, SD	AMJ	FMA,MAM	FMA	NDJ,AMJ,MJJ
Elmendorf AFB, AK	OND-JFM			NDJ-FMA
England AFB, LA	OND-FMA,AMJ			OND-JFM,MJJ,JJA
Fairchild AFB, WA			DJF,JFM, MAM	MAM
FE Warren AFB, WY	NDJ,DJF,MJJ-JAS	OND	JJA	DJF,AMJ,MJJ,JAS
Ft. Benning, GA	JFM,MAM-JJA	MAM-MJJ		JFM-MAM,JJA
Ft. Knox, KY	DJF-FMA			DJF-FMA
Ft. Sill, OD	OND			NDJ-AMJ
Ft. Worth MEAC, TX			OND	JFM,FMA
Griffis AFB, NY	OND-MAM	AMJ,MJJ	AMJ,MJJ	OND,JFM-MAM
Hill AFB, UT		MAM		AMJ

Table 8. Continued

Station	El Niño		El Viejo	
	Less IFR	More IFR	Less IFR	More IFR
Hunter AAF, GA	JAS	JAS	OND,JAS	NDJ-FMA
Keesler AFB, MS	DFJ,JFM	OND		OND-AMJ
Kelly AFB, TX	NDJ	AMJ	OND,NDJ	NDJ-FMA,AMJ
Langley AFB, VA	NDJ-JFM	FMA-AMJ		OND-DJF,AMJ-JAS
MacDill, FL	DJF		DJF	MJJ,JJA
Malmstrom AFB, MT	NDJ-JFM			OND-DJF
March AFB, CA				OND,DJF-FMA
Maxwell AFB, AL	MAM	JAS		OND-MAM
McChord AFB, WA	JFM			MAM-JAS
McGuire AFB, NJ	OND,JFM			OND-MAM,JAS
Moody AFB, GA	JFM,FMA			MAM,JAS
North Island NAS, CA	OND,DJF-FMA	MJJ		JFM-AMJ
Offutt AFB, NE		OND,MAM	MAM,JAS	
Patuxent R. NAS, MD		FMA-MJJ		JJA,JAS
Pope AFB, NC	OND-DJF,JAS	MAM		JFM,FMA,MJJ-JAS
Randolph AFB, TX		JJA	OND-DJF,MJJ	JFM,FMA
Reese AFB, TX		OND,NDJ	OND,NDJ	AMJ
Scott AFB, IL	DJF,JFM, MAM,AMJ			DJF,FMA, AMJ,JAS
Shaw AFB, SC	OND,MJJ-JAS	MAM		DJF-FMA,JJA,JAS
Tinker AFB, OK				NDJ-MAM,MJJ
Travis AFB, CA		NDJ	DJF,JFM	
Tyndall AFB, FL	DJF-FMA	OND		OND-FMA,JAS

Table 9. Significance test results for snow. Seasons during which the El Niño (El Viejo) differences are significant above the 97.5% confidence level are shaded. Hatched represents El Niño difference,and stipled represents El Viejo difference. Only stations with significant seasons are included.

Station	OND	NDJ	DJF	JFM	FMA	MAM
Fairchild AFB, WA						
F.E. Warren AFB, WY						
Ft. Knox, KY						
Wright Patterson AFB, OH						
El Niño difference						
El Viejo difference						

Table 10. Difference results for snow. Each entry indicates the season, by 3 letter abbreviation in which the El Niño (El Viejo) mean exceeds the Neutral mean by at least 2% (more snow) or the El Niño (El Viejo) mean is less than the Neutral mean by at least 2% (less snow). Stations with differences between 0 and 2% are not included in the table.

Stations	El Niño		El Viejo	
	Less snow	More snow	Less snow	More snow
Andrews AFB, MD			DJF	
Cannon AFB, NM			NDJ,DJF	
Eilsen AFB, AK				OND,NDJ,DJF JFM
Ellesworth AFB, SD	NDJ,DJF		DJF	
Elmendorf AFB, AK	FMA	NDJ		NDJ,DJF,JFM
Fairchild AFB, WA	OND,NDJ,DJF JFM,FMA			OND,NDJ,DJF
F.E. Warren AFB, WY	NDJ,DJF	FMA,MAM		
Ft. Knox, KY	OND		NDJ,DJF,JFM FMA	
Griffiss AFB, NY			NDJ,DJF	
Hill AFB, UT	NDJ,DJF			OND,NDJ,DJF
Offutt AFB, NE	NDJ,DJF,JFM FMA		NDJ,DJF	
Reese AFB, TX			NDJ,DJF	
Scott AFB, IL			DJF,JFM	
Vance AFB, OK			DJF	
Wright Patterson AFB, OH	NDJ,DJF		OND,NDJ,DJF JFM,FMA	

Table 11. Conditional probability results for snow. Each entry is the season, indicated by 3 letter code, in which the probability exceeds 20%. No probabilities exceed 50%. Stations with probabilities less than 20% are not included. Less snow signifies the probablility that the mean value for the indicated season and ENSO category is less than the mean minus one standard deviation of all years. More snow signifies the probability that the mean value for the indicated season and category is greater than the mean plus one standard deviation of all years. A dash indicates all seasons between listed seasons are included.

Station	El Niño		El Viejo	
	Less snow	More snow	Less snow	More snow
Andrews AFB, MD	NDJ	NDJ	NDJ	
Cannon AFB, NM		OND-MAM	OND-JFM	
Dover AFB, TX	OND,NDJ	OND	NDJ	
Eilsen AFB, AK				NDJ,DJF,JFM
Ellesworth AFB, SD	NDJ,DJF			
Elmendorf AFB, AK	JFM,FMA	OND		DJF,JFM,FMA
Fairchild AFB, WA	OND,NDJ,FMA MAM			OND,NDJ,FMA MAM
F.E. Warren AFB, WY	OND,NDJ,DJF JFM	OND,FMA,MAM		
Ft. Knox, KY	OND		NDJ-FMA	
Griffiss AFB, NY	MAM			MAM
Hill AFB, UT		FMA,MAM	FMA	OND,NDJ,DJF
McGuire AFB, NJ	OND,NDJ,JFM MAM	OND,NDJ	OND,NDJ	
Offutt AFB, NE	DJF,JFM	MAM		
Patuxent River NAS, MD		NDJ	NDJ,DJF	
Reese AFB, TX		OND,NDJ,JFM FMA	DJF,JFM	
Scott AFB, IL	OND		NDJ,DJF	
Vance AFB, OK		NDJ		
Wright Pat. AFB, OH	MAM	MAM	OND-MAM	

Table 12. Significance test results for freezing rain. Seasons during which the El Niño (El Viejo) differences are significant above the 97.5% confidence level are shaded. Hatched represents El Niño difference, and stipled represents El Viejo difference. Only stations with significant seasons are included.

Station	OND	NDJ	DJF	JFM	FMA	MAM
Ft. Worth MEAC, TX						
Griffiss AFB, NY						
McGuire AFB, NJ						
Offut AFB, NE						
El Niño difference						
El Viejo difference						

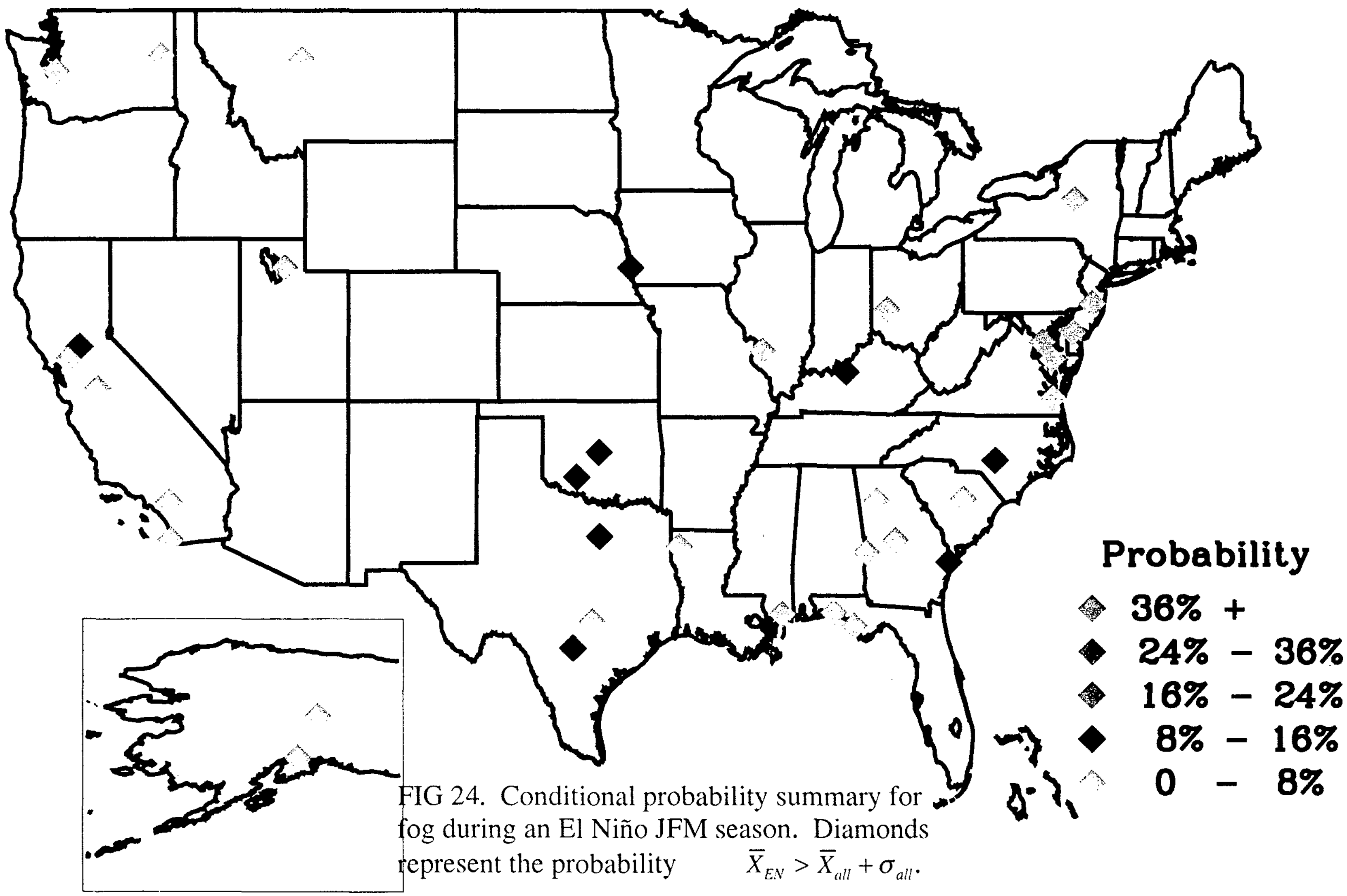


FIG 24. Conditional probability summary for fog during an El Niño JFM season. Diamonds represent the probability $\overline{X}_{EN} > \overline{X}_{all} + \sigma_{all}$.

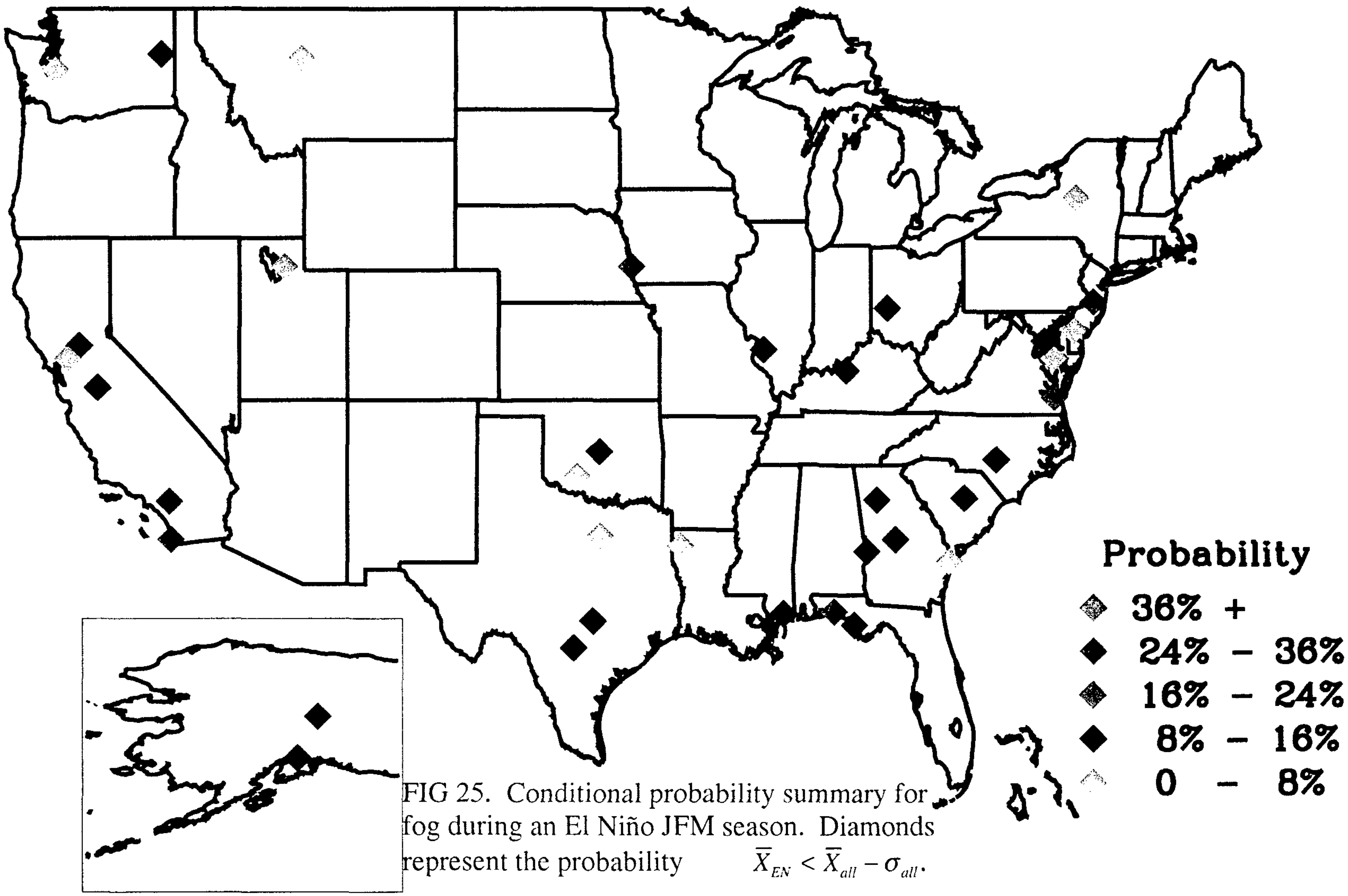


FIG 25. Conditional probability summary for fog during an El Niño JFM season. Diamonds represent the probability $\overline{X}_{EN} < \overline{X}_{all} - \sigma_{all}$.

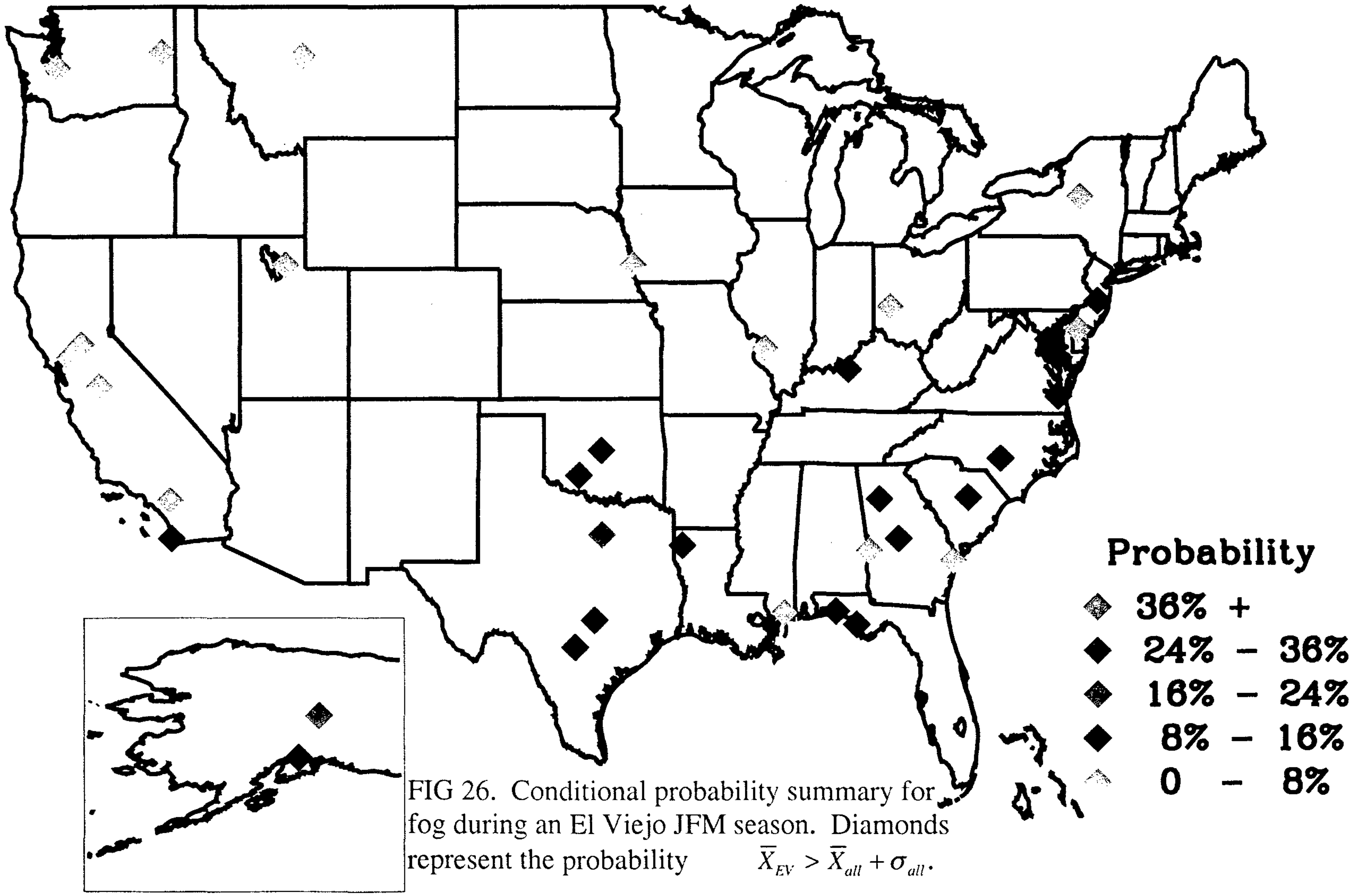


FIG 26. Conditional probability summary for fog during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} > \overline{X}_{all} + \sigma_{all}$.

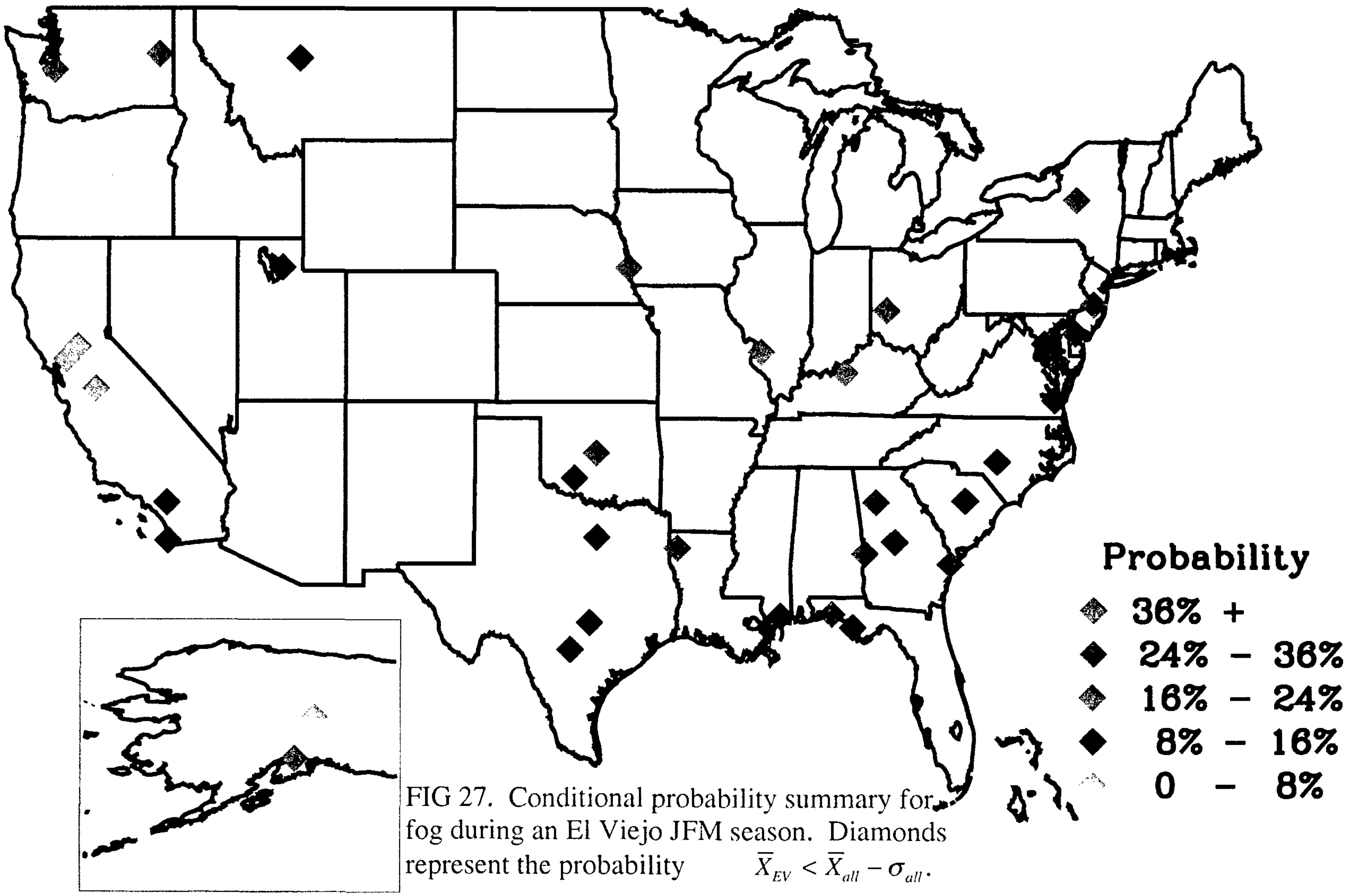


FIG 27. Conditional probability summary for fog during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} < \overline{X}_{all} - \sigma_{all}$.

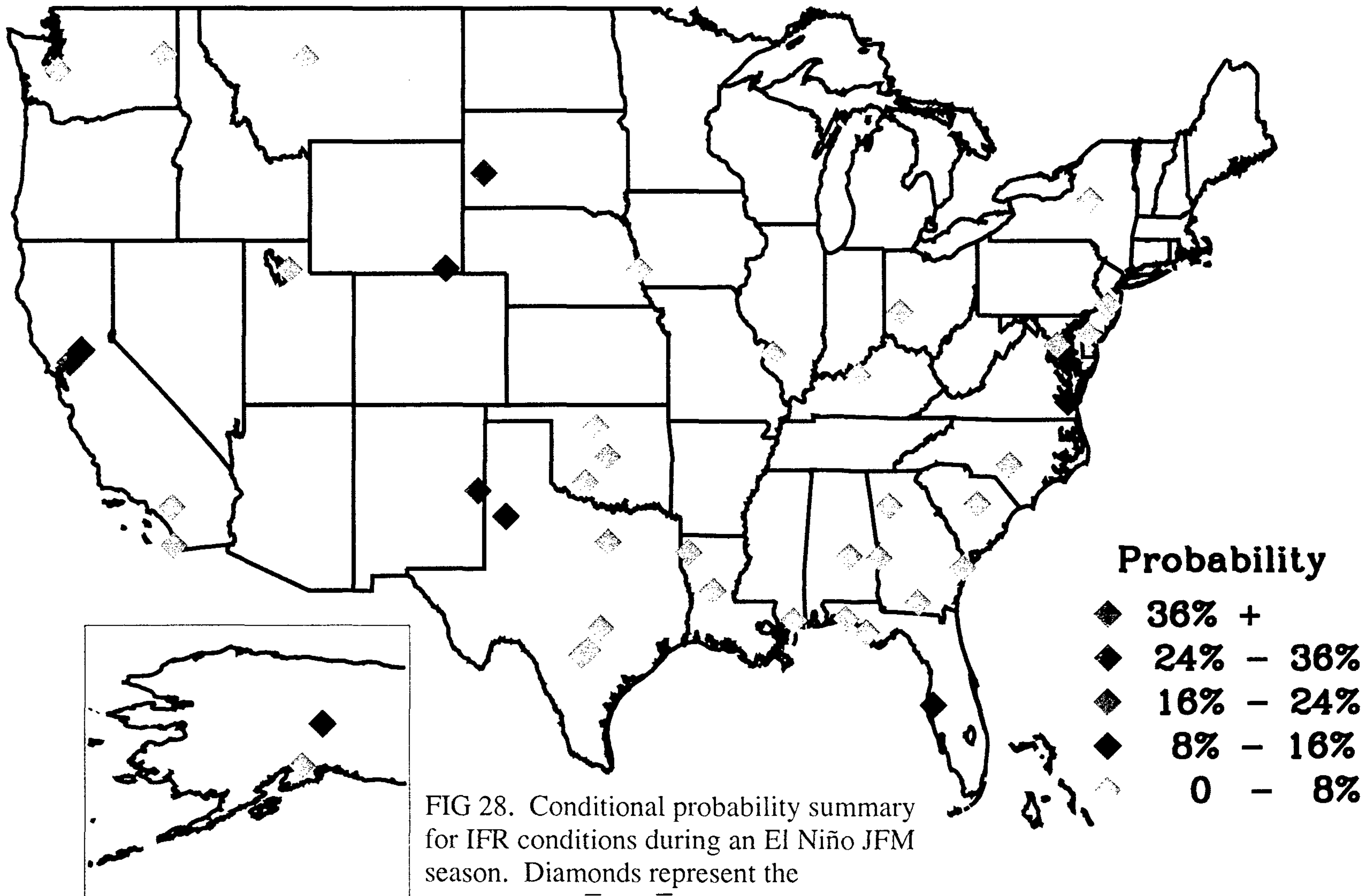


FIG 28. Conditional probability summary for IFR conditions during an El Niño JFM season. Diamonds represent the probability $\overline{X}_{EN} > \overline{X}_{all} + \sigma_{all}$.

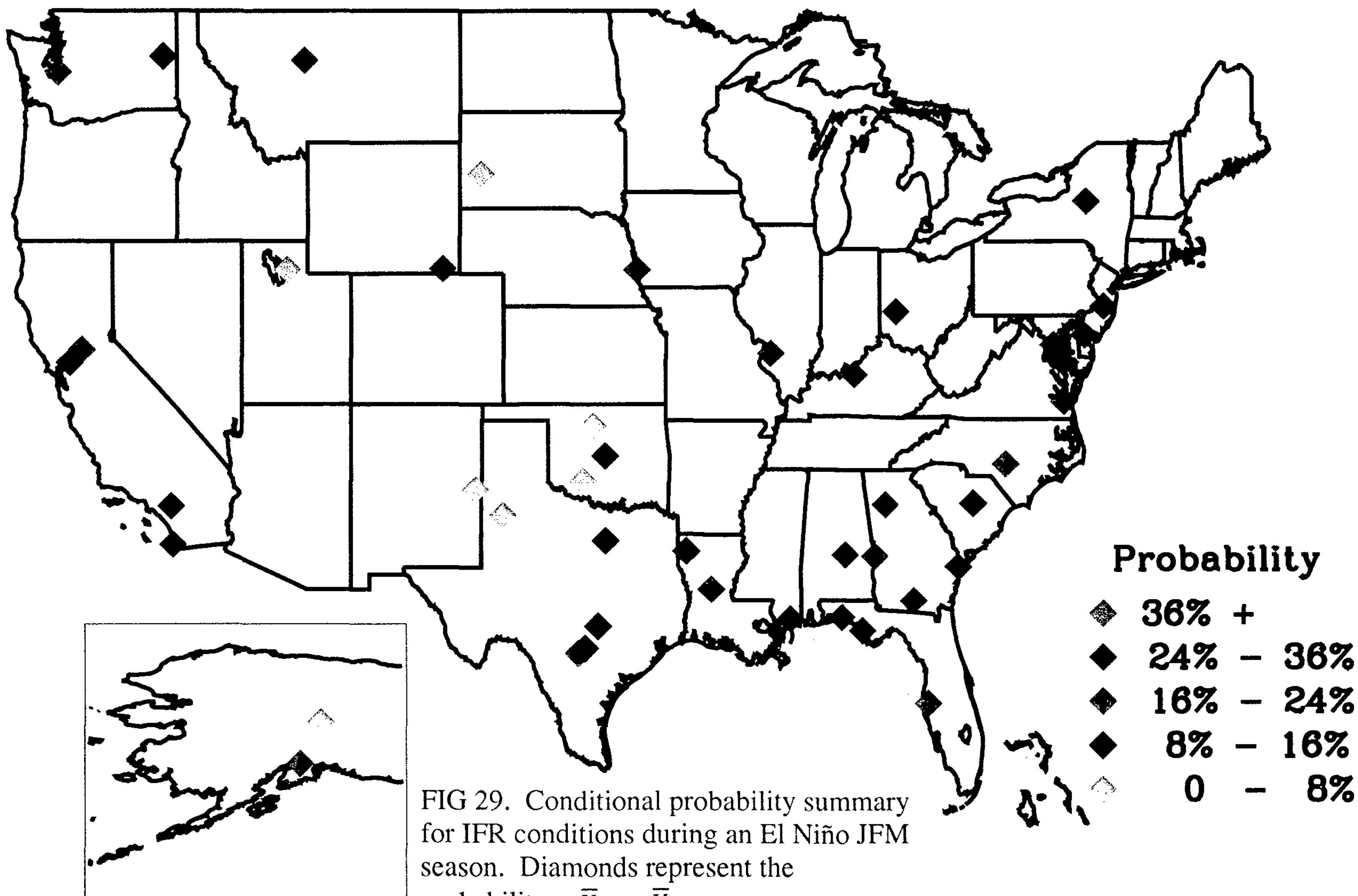


FIG 29. Conditional probability summary for IFR conditions during an El Niño JFM season. Diamonds represent the probability $\overline{X}_{EN} < \overline{X}_{all} - \sigma_{all}$.

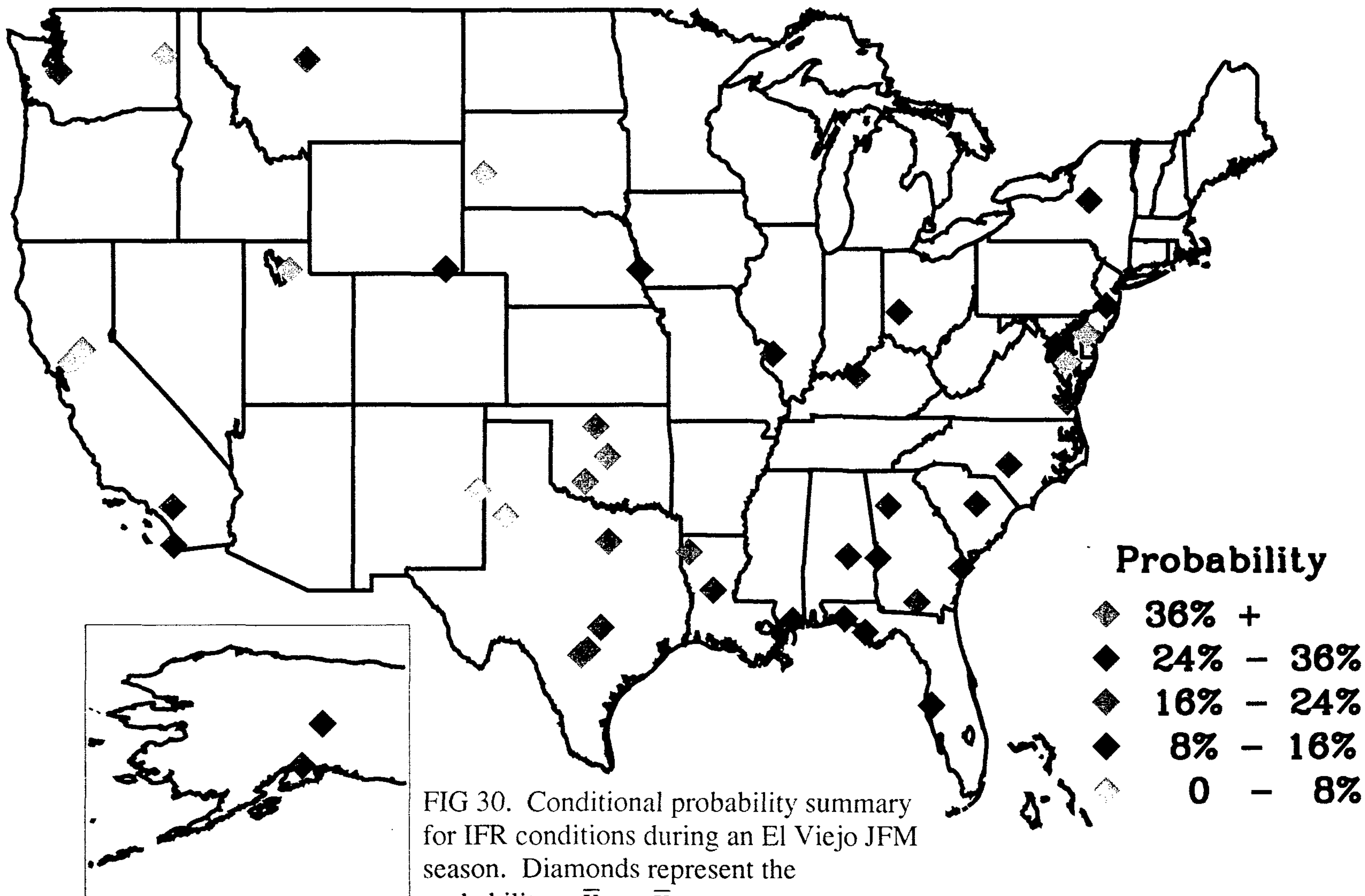


FIG 30. Conditional probability summary for IFR conditions during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} > \overline{X}_{all} + \sigma_{all}$.

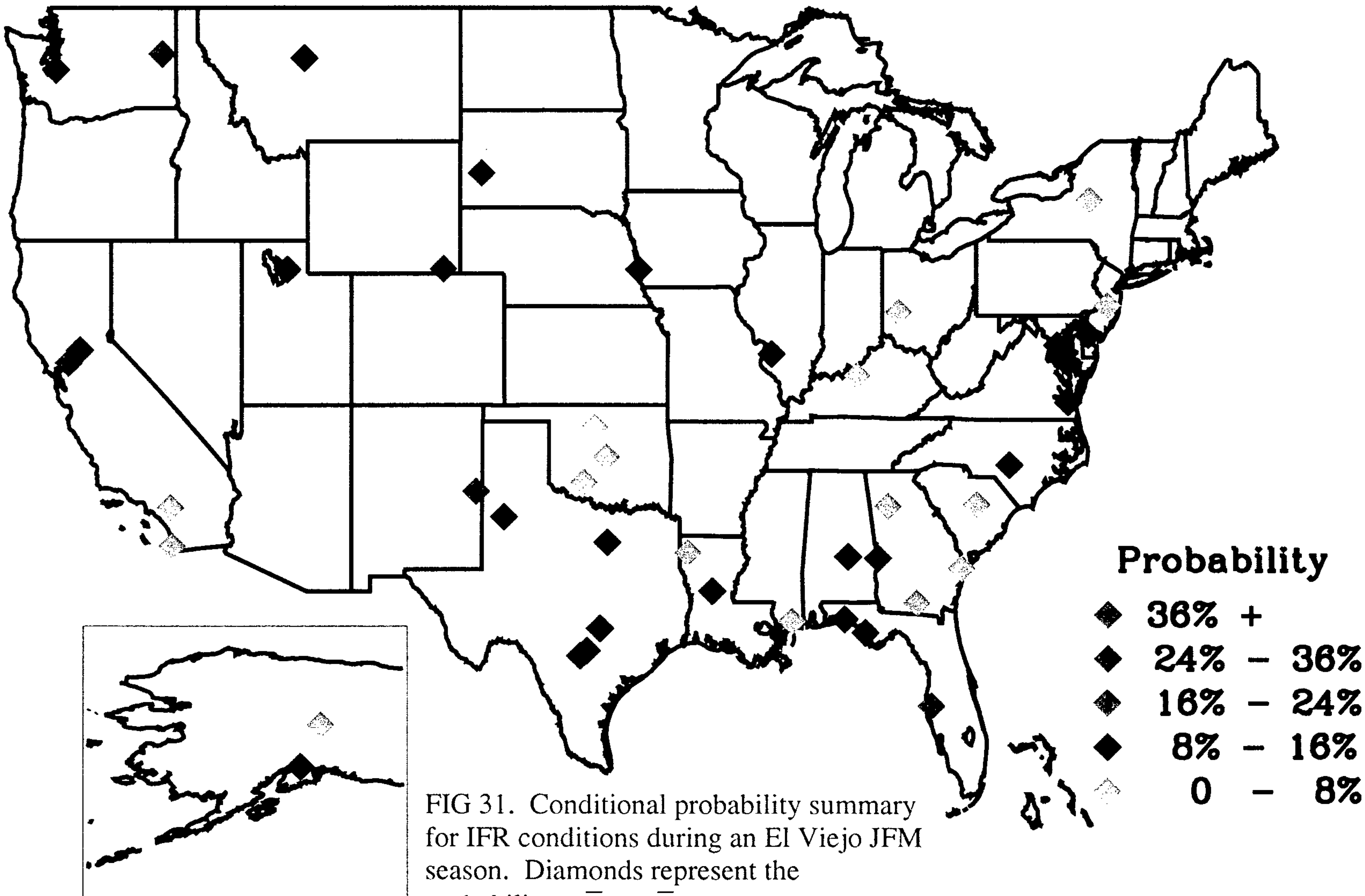


FIG 31. Conditional probability summary for IFR conditions during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} < \overline{X}_{all} - \sigma_{all}$.

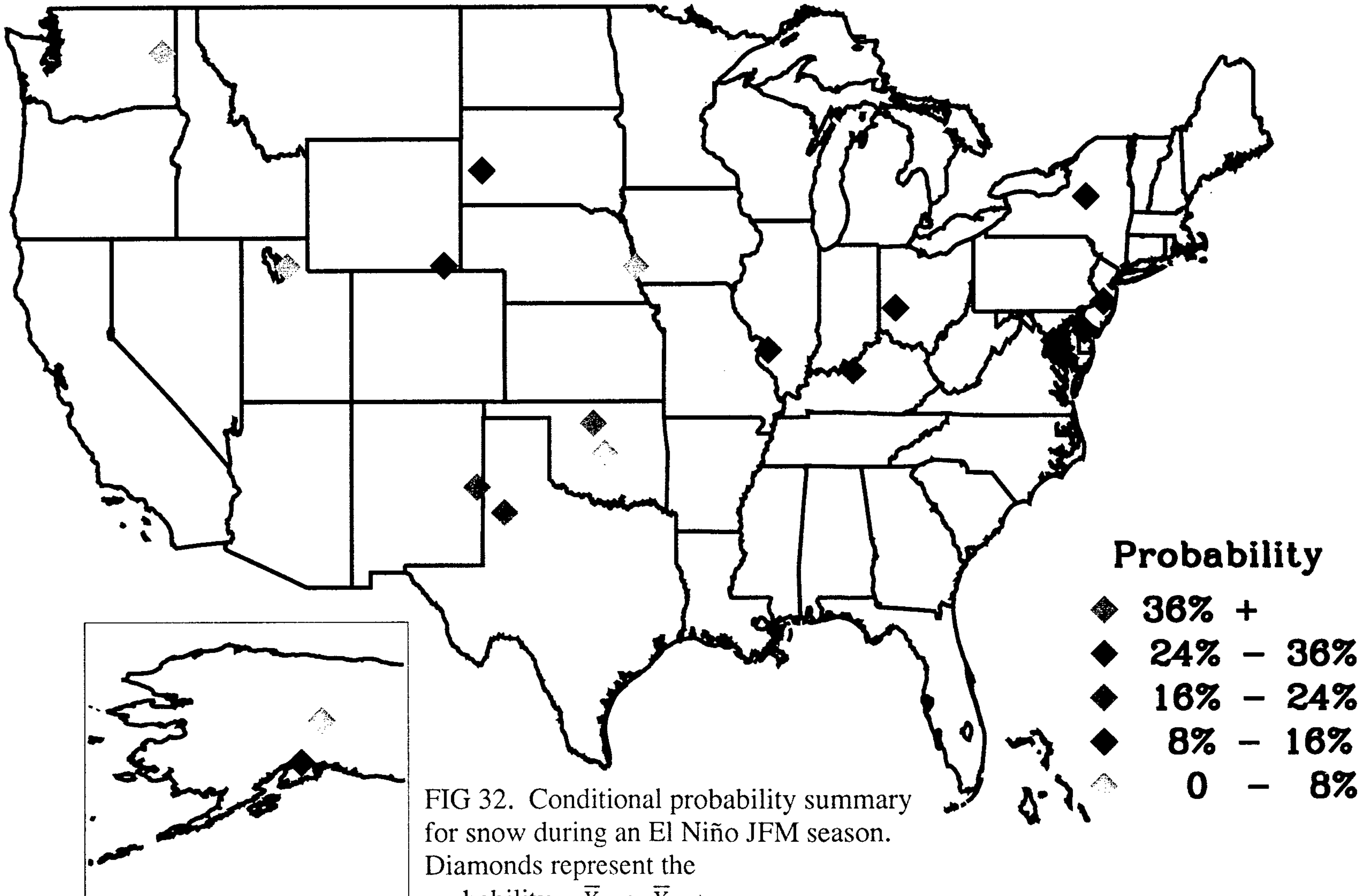


FIG 32. Conditional probability summary for snow during an El Niño JFM season. Diamonds represent the probability $\overline{X}_{EN} > \overline{X}_{all} + \sigma_{all}$.

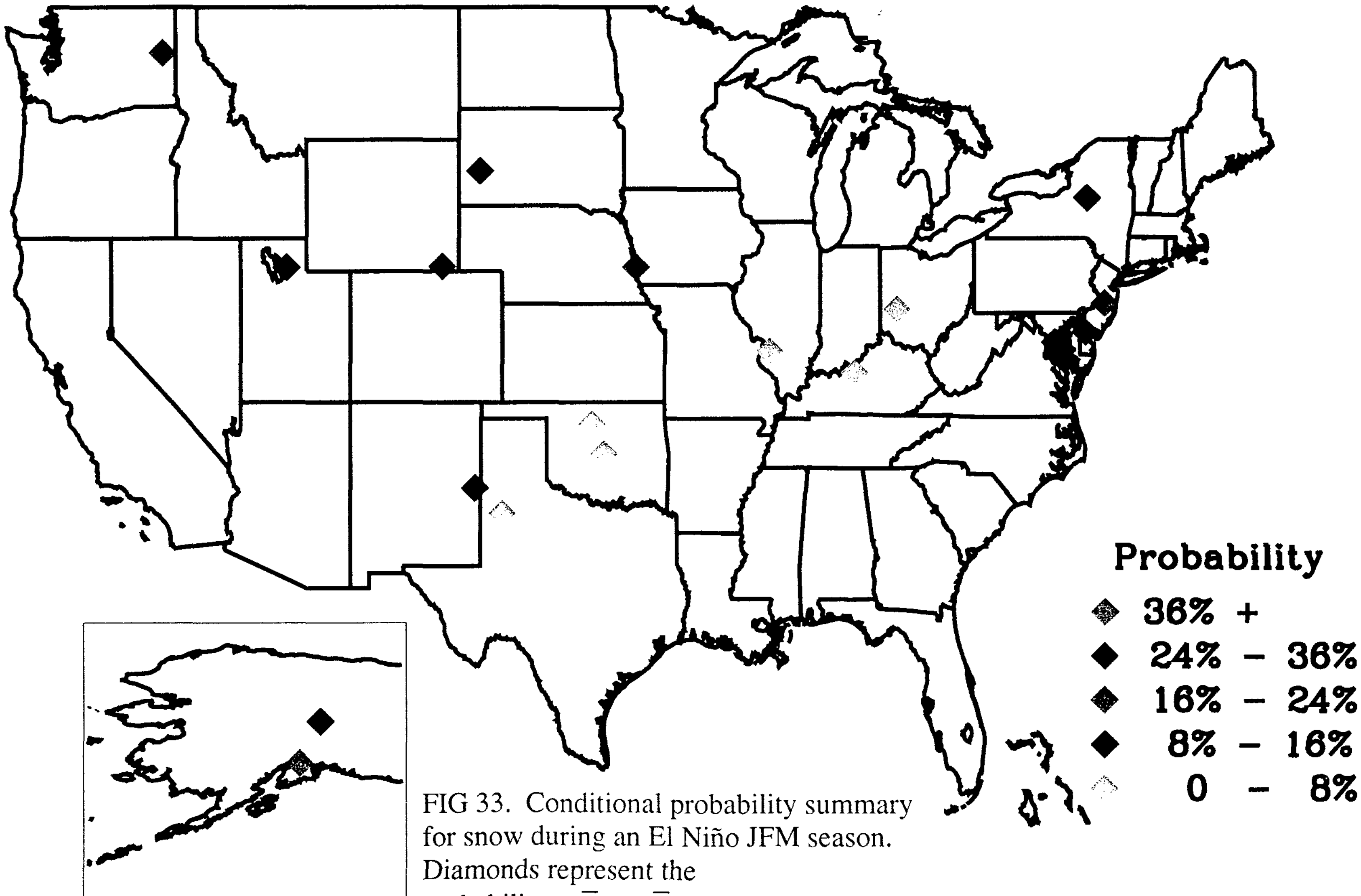


FIG 33. Conditional probability summary for snow during an El Niño JFM season. Diamonds represent the probability $\overline{X}_{EN} < \overline{X}_{all} - \sigma_{all}$.

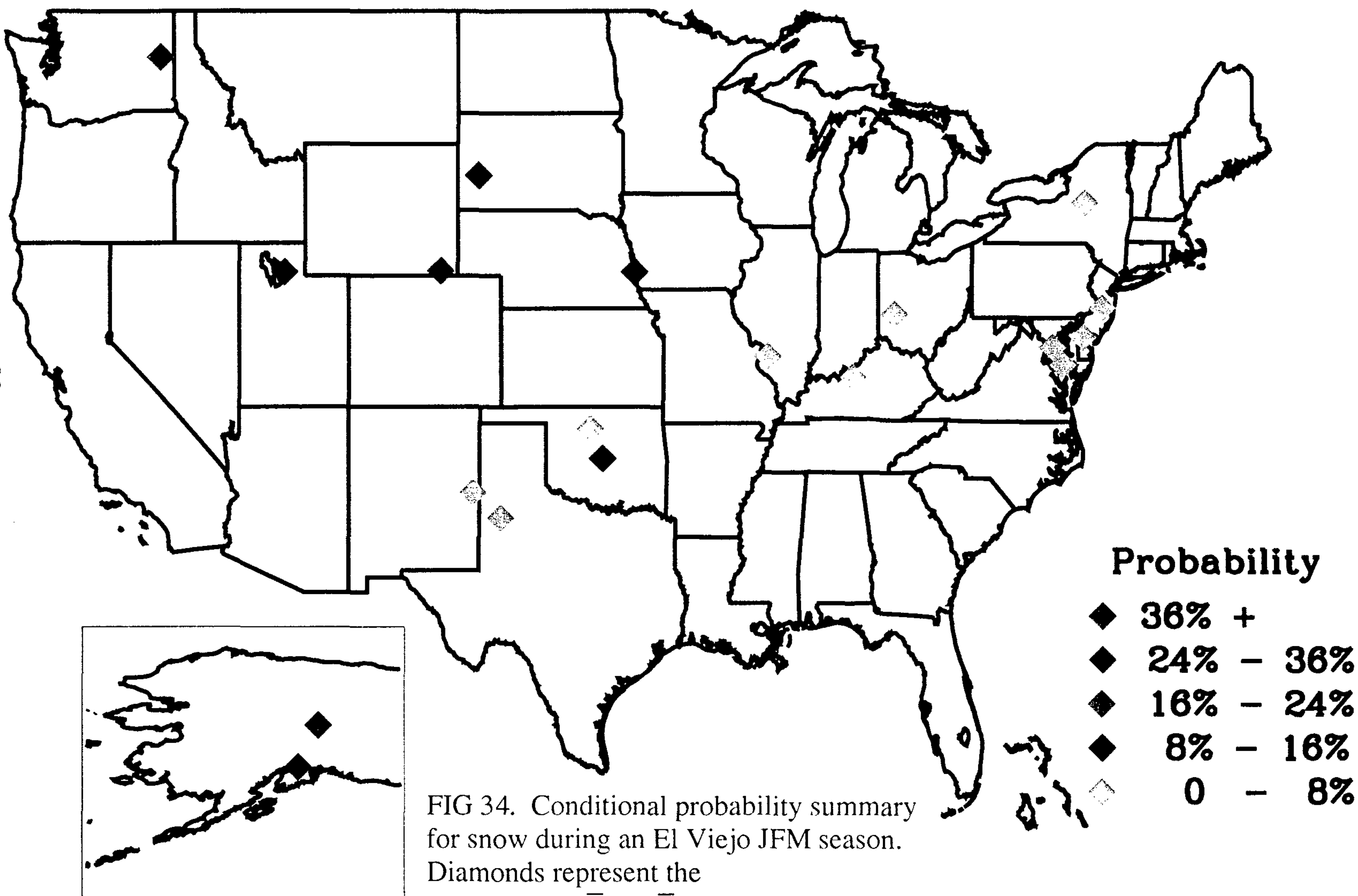


FIG 34. Conditional probability summary for snow during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} > \overline{X}_{all} + \sigma_{all}$.

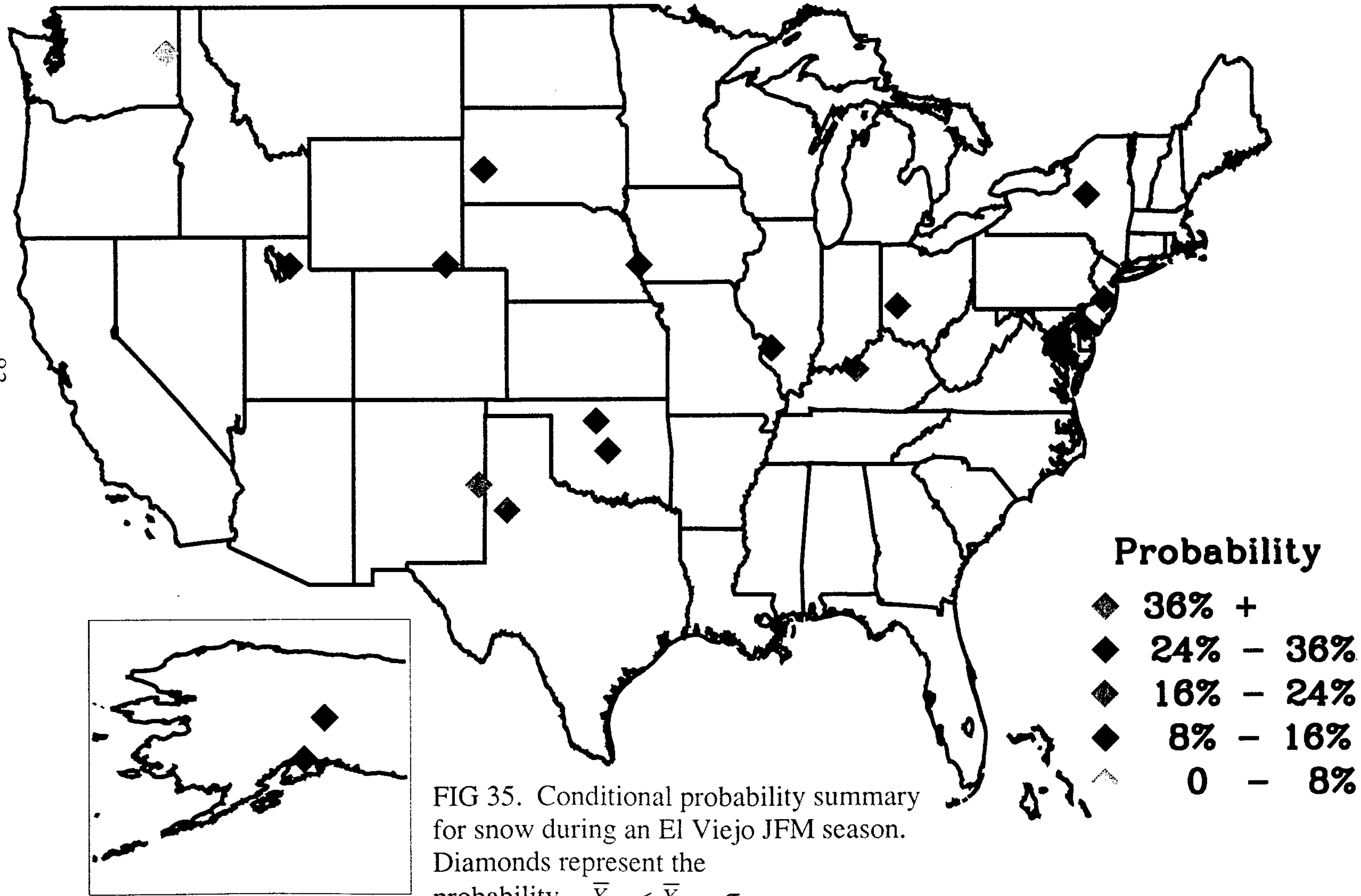


FIG 35. Conditional probability summary for snow during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} < \overline{X}_{all} - \sigma_{all}$.

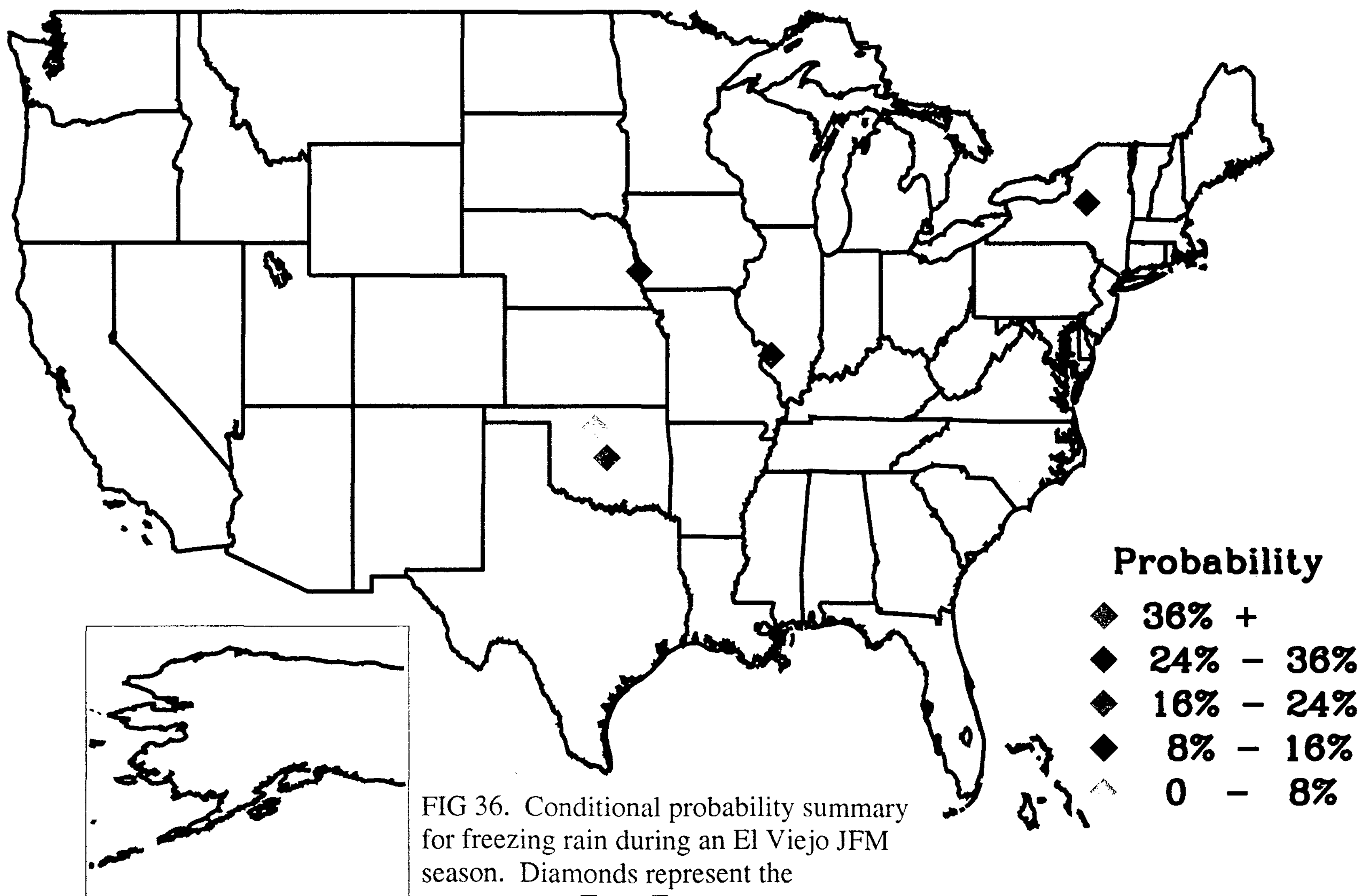


FIG 36. Conditional probability summary for freezing rain during an El Viejo JFM season. Diamonds represent the probability $\overline{X}_{EV} > \overline{X}_{all} + \sigma_{all}$.

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